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MILITARY HANDBOOK

DESIGN HANDBOOK

FOR

LINE OF SIGHT MICROWAVE

COMMUNICATION SYSTEMS

SLHC

DEPARTMENT OF DEFENSE
WASHINGTON 25, D.C.

Design Handbook for Line of Sight Microwave Communication System

1. This standardization handbook was developed by the Department of Defense in accordance with established procedure.

2. This publication was approved on 15 November 1977 for printing and inclusion in the military standardization handbook series.

3. This document provides basic and fundamental information on line of sight radio system It will provide valuable information and guidance to Personnel concerned with the preparation of specifications and the procurement of line of sight radio systems. The handbook is not intended to be referenced in purchase specifications except for information purposes, nor shall it supersede any specification requirements.

4. Benficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to:

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FORWARD

This handbook provides considerations for use in the design, installation, operation and acceptance of Department of Defense(DOD) long haul DCS Line-of-Sight (LOS) analog microwave communications facilities.

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CHAPTER 1

SCOPE

Section 1.1 GENERAL.

1.1.1 This handbook for line-of-site (LOS) radio systems include techniques and procedures necessary for communications engineers to design systems utilizing state-of-the-art principles existing now. Information in this handbook is applicable to systems operating at frequencies between approximately 1 to 40 GHz, and outline the design methods to be employed in the engineering of LOS facilities so that they will operate in accordance with the required criteria. In order for an actual system to meet Defence Communication Agency (DCA) standards and objectives, the appropriate and current Military Standards (section 2.1), DCA circulars, CCIR Recommendations or service-wide publications (section 2.2) must be consulted as source documents for performance criteria. The referenced standards are updated as the state of the art improves, and such improved performance standards are not necessarily reflected in the examples given in this handbook.

1.1.2 The handbook categorized the basic information which must be supplied to, or assumed by, the engineer before he can determine system feasibility and start the design procedures.

1.1.3 Information is provided first on how to start the design work with a preliminary selection of sites and routes based on stated performance requirements. Selection is aided by obtaining preliminary path profiles and calculating initial transmission loss values.

1.1.4 Procedures are then established for planning and performing field surveys and using the results obtained for further establishing site and route preference.

1.1.5 Worksheets and procedures are presented for the detailed evaluation of individual links after provision is made for adequate terrain clearance. Various equipment alternatives are discussed and quantitative data for equipment planning are supplied.

1.16 Atreatment of overall system planning is presented under the basic topics of system layout, frequency allocation, intra-system interference, allowable link noise quota, and performance predictions.

Section 1.2 PURPOSE.

1.2.1 This handbook is intended to assist suitably qualified personnel in designing microwave systems to current state-of-the-art standards, but cannot be considered a substitute for experience and education in the engineering of such systems.

1.2.2 Various aspects of design problems are considered and several alternatives to their solution are presented wherever possible. Although the handbook draws information and ideas from many sources, it is not to be used exclusively. Serious or special problems may require that other applicable sources of information be consulted.

Section 1.3 APPLICATION.

1.3.1 The handbook applies to microwave line-of-sight (LOS) radio systems which are used to provide multichannel communication between fixed locations. Such point-to-point systems generally use a carrier frequency in the range of 1 to 40 GHZ over paths typically from 10 to 100 km long. Antenna heights above ground are usually adequate to provide line-of-sight paths under most circumstances, but seldom exceed 100 m. In some cases, passive reflectors are employed to obtain line-of-sight conditions.

1.3.2 Individual paths or links are integrated into a system which may, through the use of repeaters, extend over various types of terrain for a distance of several hundred kilometers. The transmitters are normally low power, from 0.1 to 10 W, and with companion receivers share the use of high-gain directional parabolic antennas between 1 and 5 m in diameter, or various types of horns having equivalent gain and beamwidth characteristics. These systems provide the transmission means for communication traffic consisting of voice, teletype, facsimile, digital data, and of visual displays.

1.3.3 The microwave carrier must be modulated by many information streams which are separated by multiplexing processes. Primarily two basic kinds of multiplexing are used on microwave LOS links, namely frequency division multiplex and time division multiplex. Frequency division multiplex (FDM) keeps the information streams separated using frequency division by means of bandpass filters. Time division multiplexing (TDM) uses logic circuits to isolate the channels from each other in time.

Section 1.4 OBJECTIVES.

1.4.1 The main objective of this handbook is to provide methods for microwave LOS link and system design. Major topic areas discussed are: obtaining detailed path profiles, path loss calculations, service probability and fading range estimates, radio interference investigations, adherence to DCA noise standards, and link equipment requirements. Graphs, basic equations, and tables are provided for optimizing the design through the use of trade-off studies in order to insure that the functional, reliability, and safety requirements are met. Most of the design procedures and engineering analyses can be performed using a slide rule; more accurate calculation procedures are required for great circle calculations.

1.4.2 Certain analyses are performed to insure the compatibility of the individual links with the total communication system objectives. These are mainly (1) system performance predictions based on the composite characteristics of the individual links, (2) the compatibility analyses of the individual frequency assignments within the band, and (3) the specification of branch and terminal requirements so that the linking of branches at the sites is achieved properly.

Section 1.5 GENERAL INSTRUCIONS.

1.5.1 This handbook may be used to provide (1) a chronological order of procedures for designing the system, and (2) information on specific topics which may appear as particular design problems.

1.5.2 The organizational block diagrams (section 1. 6) should be used as an aid in defining a chronological order of procedures. They show the sequence of design tasks and indicate required information or assumptions for each major step.

1.5.3 For information on specific topics, the table of contents and the index should be consulted. Many topics are considered from several points of view or at different stages in the design and, therefore, are discussed at more than one place in the handbook. The technical description contained in Chapter 6 or in worksheets provided are needed for some of the technical processes. Examples of the worksheets may appear in the text, and blank worksheets are included in Chapter 6.

Section 1.6 ORGANIZATION.

1.6.1 The main body of the handbook (Chapter 4) is organized as shown in the following block diagrams (figures 1.1 to 1.5). They indicate that subject matters are discussed in the handbook as they would most probably occur chronologically in actual system design. If the reader has knowledge of where in LOS system design a problem is to be considered, he may view the diagrams and acquaint himself with specific or related tasks for a further understanding of that particular problem.

1.6.2 Major topics are numbered using periods to separate sections and subsections. These numbered topics appear in the table of contents. Each paragraph in the following chapters is individually numbered.

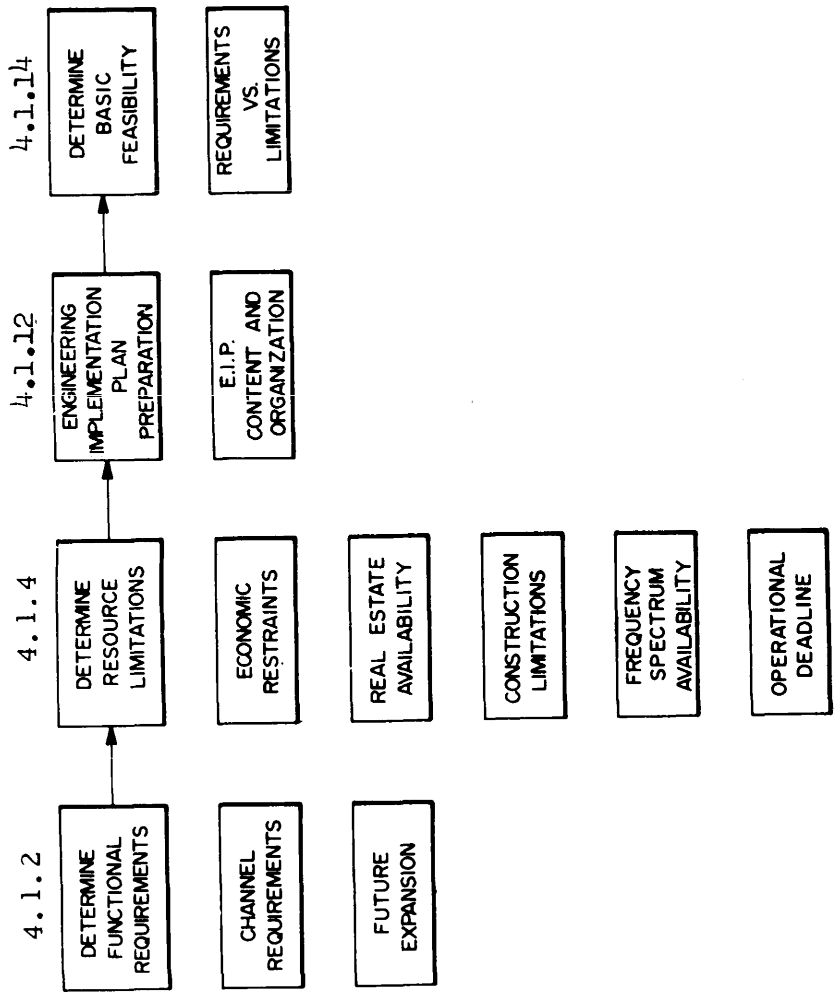

Figure 1-1 Flow Chart for Section 4.1 (Starting Design)

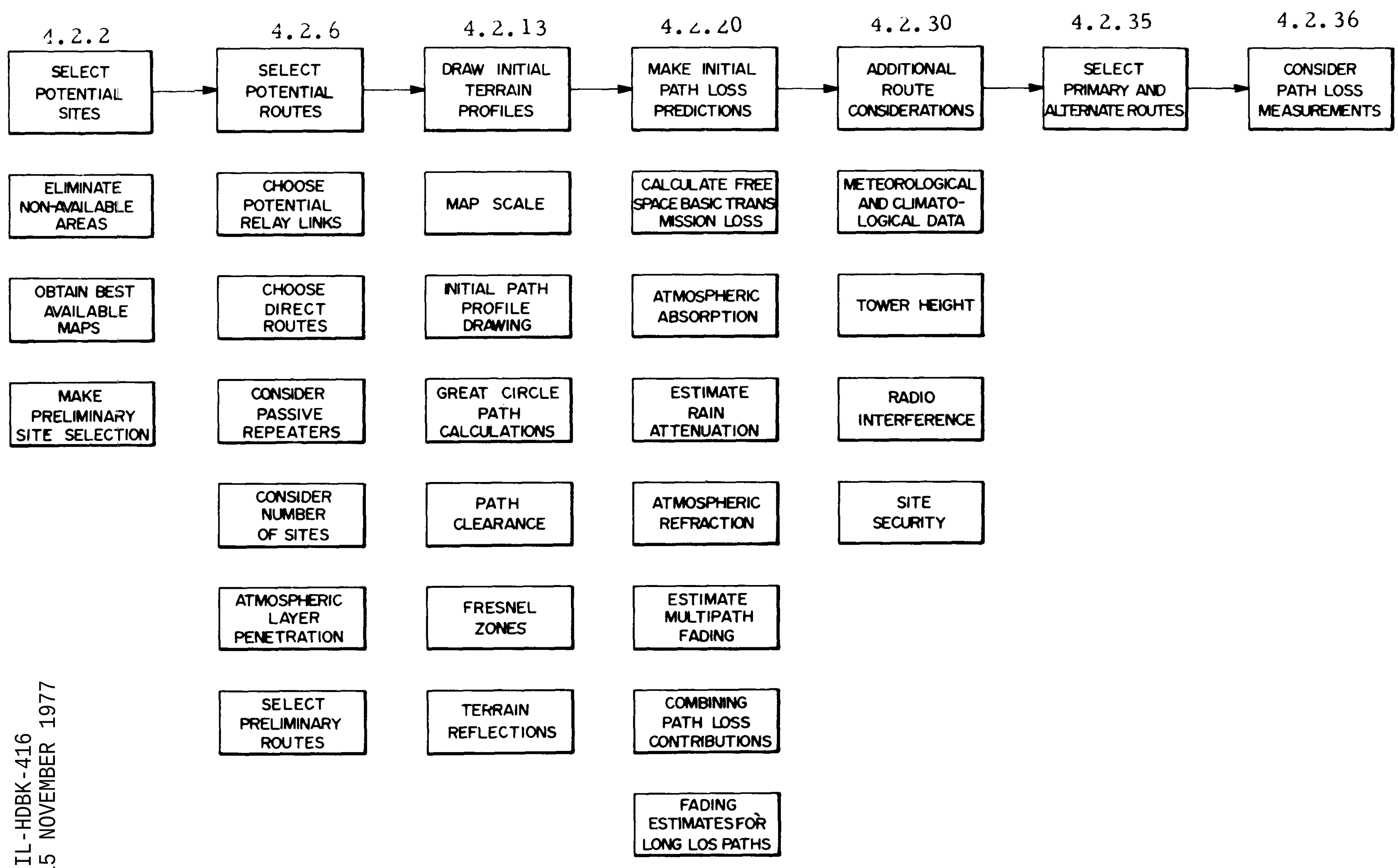

Figure 1-2 Flow Chart for Section 4.2 (Study of Route Alternatives)

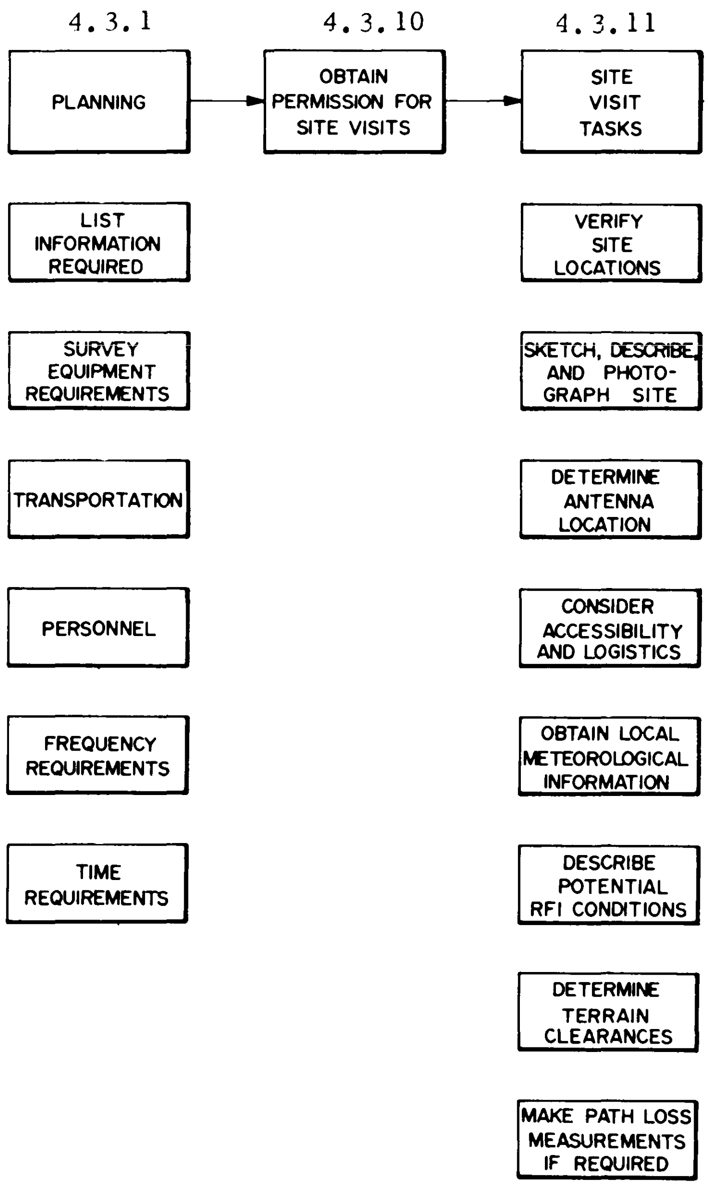

Figure 1-3 Flow Chart for Section 4.3 (Field Survey)

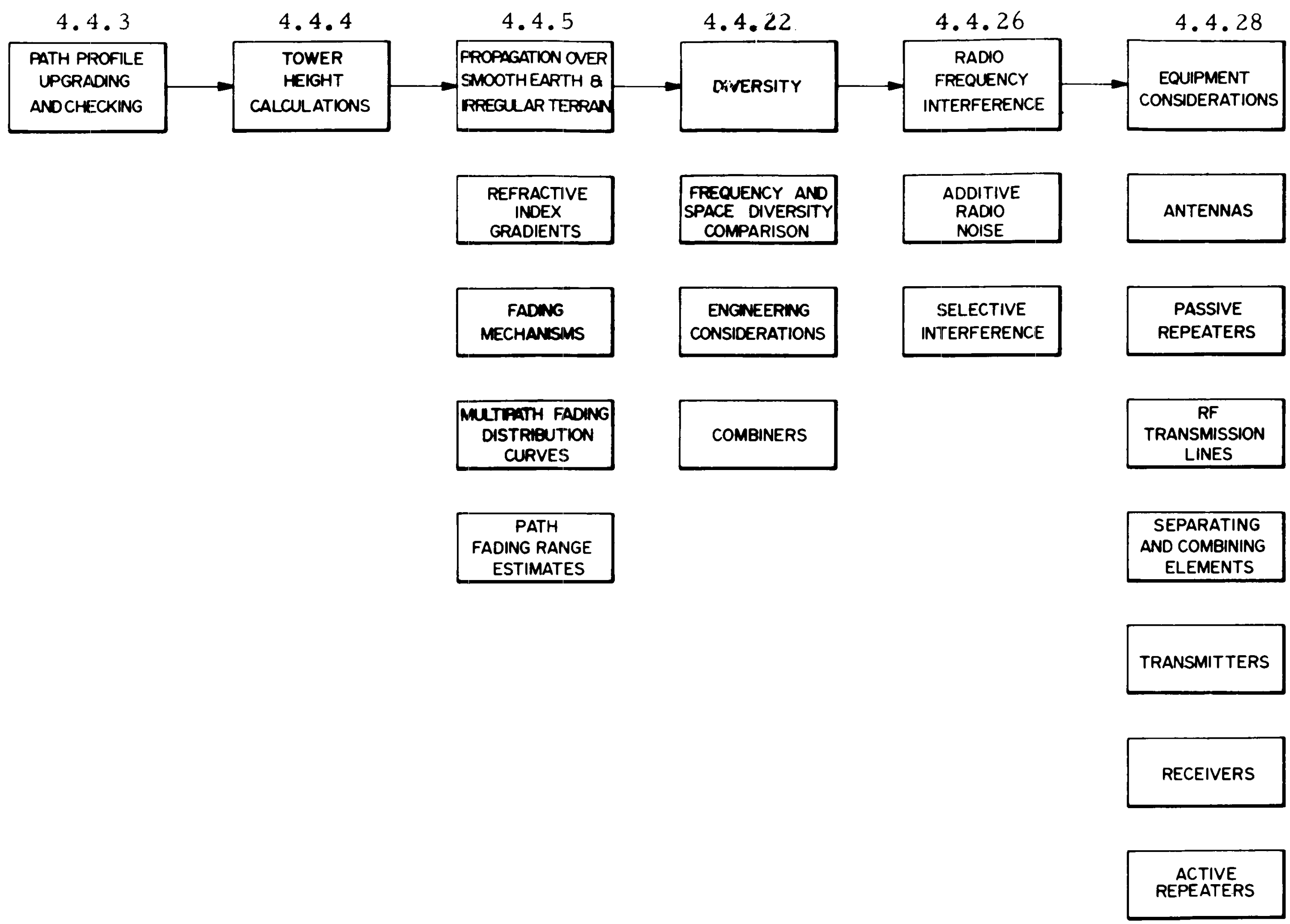

Figure 1-4 Flow Chart for Section 4.4 (Link Design)

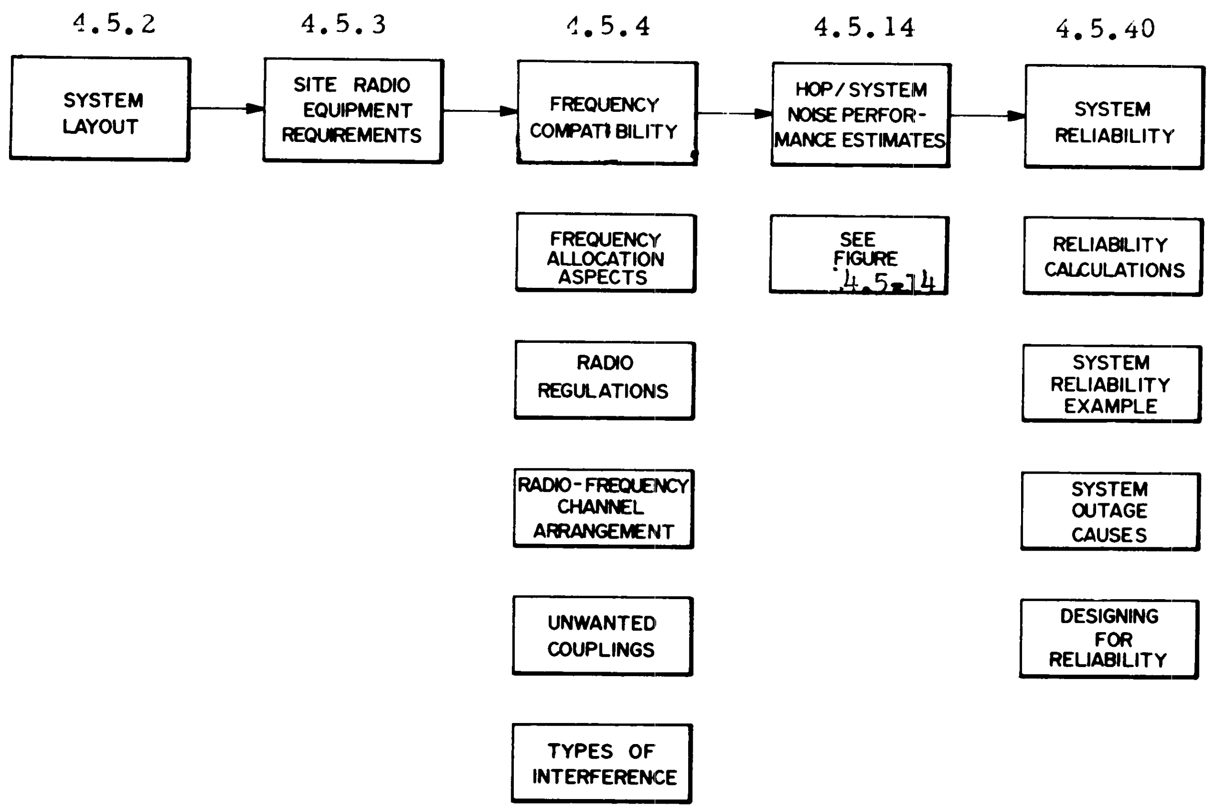

Figure 1-5 Flow Chart for Section 4. 5 (Integrating Link Design into System Design)

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CHAPTER 2

REFERENCED DOCUMENTS

2.1 Military Standards.

MIL-STD-188	Military Communication System Technical Standards (to be replaced by MIL-STD-200 series)
MIL-STD-188-100	Common Long Haul and Tactical Communication System Technical Standards
MIL-STD-188-300	Subsystem Design and Engineering Standards for Technical Control Facilities
MIL-STD-188-311	Technical Design Standards for Frequency Division Multiplexer
MIL-STD-188-313	Subsystem Design and Engineering Standards and Equipment Technical Design Standards for Long-Haul Communcations Transversing Microwave LOS Radio and Tropo-spheric Scatter Radio
MIL-STD-188-340	Long Haul Communications Standards Equipment Technical Design Standards for Voice Orderwire Multiplex

MIL-STD-188-342	Standards for Long Haul Commun-cations Equipment Technical Design Stanards for Voice Frequency Carrier Telegraph (FSK)
MIL-STD-188-346	Standards for Long Haul Communica-tions, Equipment Technical Design Standards for Analog End Instru-ments and Central Office Ancillary Devices
MIL-STD-188-347	Standards for Long-Haul Communica-tions Equipment Technical Design Standards for Digital End Instru-ments and Ancillary Devices
MIL-STD-461	Electromagnetic Interference Charac-teristics Requirements for Equipment
MIL-STD-462	Electromagnetic Interference Chara-teristics, Measurement of
MIL-STD-463	Definitions and Systems of Units, Electromagnetic Interference Tech-nology
MIL-STD-633	Mobile Electric Power Engine Gener-ator Standard Family characteristics Data Sheets

MIL-STD-1327	Flanges, Coaxial and Waveguide; and Coupling Assemblies, Selection of
MIL-STD-1328	Couplers, Directioal (Coaxial Line, Waveguide, and Printed Circuit) Selection 01
MIL-STD-1358	Waveguides, Rectangular, Ridged and Circular, Selection of
MIL-STD-1381	Technical Electronic Terms and Definitions

2.2 Military Handbooks.

(c) MIL-HDBK-232	Red/Black Engineering-Installation Guidelines (U)
MIL-HDBK-411	Long Haul Communications (DCS) Power and Environmental Control for Physical Plant
MIL-HDBK-417	Facility Design for Tropospheric Scatter

2.3 Other Referenced Documents.

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CHAPTER 3.0

3.0 TERMS AND DEFINITIONS (MIL-STD 188-120)

3.1 Symbols

A Area

A Parameter A or $\frac{\delta F}{f_m}$

A Total attenuation attributable to atmospheric and terrain effects

a Terrain factor

A_a Atmospheric absorption

A_c Circulator loss

A_f Transmit forward feeder attenuation

A_i Isolator loss

A_r Transmit reverse feeder attenuation

A_{tl} Transmission line loss

b Bandwidth

b Climate factor

B_b Baseband bandwidth

B_c Bandwidth of the RF channels

b_c Usable voice channel bandwidth

B_{IF} Receiver IF bandwidth

B_o Mid frequency separation

b_{rf} RF bandwidth

C Velocity of light

C RF carrier level

C/N	Carrier-to-noise ratio
C_r	Fresnel zone clearance
D	Antenna diameter
D	Maximum dimension of an antenna aperture
d	Great circle path distance
d	A side dimension of a reflector
d_n	Nominal path length
d_s	Lateral separation of route diversity paths
E	Electric field
ERP	Effective radiated power
e_s	Saturation vapor pressure
F	Receiver noise figure
f	Frequency
F_{am}	Median operating noise factor
f_ℓ	Lowest frequency in the baseband
f_m	Maximum modulating frequency
F_n	nth Fresnel zone
G	Geometric mean of the transmitting and receiving antenna power gains
G	Antenna gain above isotropic
G_p	Gain of the projected aperture of a passive repeater

H	Height
h	Vertical distance
h_s	Average height of the two, path terminals above msl
I_d	Diversity improvement
I_p	Pre-emphasis improvement
K	K is a measure of the anisotropic scattering of the random components by the terrain
k	Ratio of effective earth's radius to actual earth radius, or the equivalent earth's radius factor
k	Boltzman's constant, 1.3804×10^{-20} millijoules/^{0}K
k TBF	Receiver noise threshold
L	Transmission loss
L_{bf}	Basic free-space transmission loss
LF	RMS load factor
lf	Numerical RMS load factor
L_{of}	Free-space path loss
L_p	Median value of power loss between antenna terminals on a passive repeater link
L_t	Transmission line length (transmitter)
M_F	Fading depth exceeded below free space
M_f	Fade margin
N	$N = (n-1) 10^6$ (refractivity)

N	Number of channels
n	Radio refractive index
n	Number of equivalent voice channels
N_e	Equipment intermodulation noise
NF	Noise figure
N_f	Feeder echo noise
N_{im}	Total path independent non-linear noise
NPR	Noise power ratio
N_s	Surface refractivity
N_t	Thermal noise
N_{te}	Emphasis - improved thermal noise
N_{Tmed}	Total median noise
N_{TTH}	Total noise at FM threshold
N_{tTH}	Emphasis - improved thermal noise at threshold
$N_{tTH}(E,D)$	Diversity and emphasis - improved thermal noise at threshold
P	Pressure
P_e	Probability of error
PF	Peak factor
pf	Numerical peak factor
P_{mf}	Percent of year that fades exceed a specified depth below free-space loss
P_r	Received RF signal level

P_{rTH}	Received signal level at FM threshold
P_t	Transmitter power
r	Distance
r	Echo amplitude
r	Radius of curvature of the radio ray
r	Signal level
$\tilde{r}$	rms value of the signal level
R	Reliability
RH	Relative humidity in percent
RL_t	Transmit return loss
R_n	nth Fresnel zone radius
r_o	Radius of the earth ($r_o \approx$ 6370 km)
R_r	Rainfall rate
S	Signal level
S	The RMS Rayleigh signal level in decibels above the RMS multipath, $\sqrt{1 + \alpha^2}$
S/D	Signal-to-distortion ratio
T	Temperature (°K)
v	Velocity of propagation
V	Voltage
VSWR	Voltage standing wave ratio

Z $Z = 20\ \log_{10}\left(\frac{r}{\tilde{r}}\right)$

Z Impedance

α	Angle of incidence
α	Attenuation
α	Reflection coefficient
β	Take-off-angle
γ_{oo}	Atmospheric absorption due to oxygen
γ_r	Rain attenuation per unit length
γ_{wo}	Atmospheric absorption due to water vapor
δ	RMS per channel deviation
ΔF	Peak carrier deviation
$\frac{\Delta n}{\Delta h}$	Radio refractive index gradient
$\frac{\Delta N}{\Delta h}$	Refractivity gradient
$\Delta\phi$	Phase deviation
$\Delta\omega$	Angular frequency deviation
η	Efficiency of antenna aperture
θ	Angle of arrival
θ	Angle of incidence
θ_u	Beamwidth (half power)
θ_n	Beamwidth between first null points
λ	Wavelength
λ_c	Cut-off wavelength

ρ	Sum of reflection coefficient magnitudes
σ	Reflection coefficient
σ	Standard deviation of the heights of surface irregularities
τ	Echo delay time
χ	Incident angle of the reflected ray
Ω	Baseband angular frequency

CHAPTER 4

SYSTEM DESIGN

Section 4.0 INTRODUCTION.

4.0.1 Chapter 4 contains information necessary for designing the line-of-sight microwave system with the exception of facility design criteria such as detailed information on physical plant layout, primary power, tower and antenna structure, safety, etc. , which is presented in Chapter 5.

4.0.2 Section 4.1 discusses gathering information on functional requirements and resource limitations; it also discusses the content of the engineering implementation plan which must be prepared as the design effort proceeds. Section 4.2 describes a systematic approach to the selection of sites and routes which tends to grade them in such a way as to prevent good candidate paths from being overlooked or eliminated. On the basis of grading described in section 4.2, certain paths and sites are selected for additional investigation by field survey. Field survey techniques and requirements are considered in section 4.3. Information on path profiles and site conditions is used in the detailed link design, section 4.4. Path geometry, local meteorological conditions, potential interference sources, and basic microwave equipment are involved. Section 4.5 takes up the problem of integrating the links into a compatible system. This task includes system layout, frequency allocation, intra-system interference and the preparation of system performance predictions. Chapter 4 is organized as shown in the flow diagrams of section 1.6.

4.0.3 Quantative information on the topics described above is contained throughout the various sections of Chapter 4. This information is contained primarily in the form of graphs and tables for ease of application. Several equations, however, were considered necessary.

Units and definitions of terms are supplied in the immediate context of the equations. In cases where descriptive material describing the same topic appears in more than one place in the text, we have attempted to supply suitable cross-referencing.

4.1 STARTING THE DESIGN

4.1.1 General

4.1.1.1 At the start of LOS microwave system design, several copies of an outline map of the general area to be served should be obtained. An example of such a map is shown later on in figure 4.5-1. One or more of these maps can be used to record information relevant to the system as it becomes available. These outline maps can also be made to serve as an index to more detailed information about the system, e. g., an approximate grid of suitable larger-scale maps can be drawn on the outline map, and site designations can be shown at their approximate location with more detailed information provided in tabular form. Information on functional requirements (sec. 4.1.2) and resource limitations (sec. 4.1.4) should be collected, and organized to start the Engineering Implementation Plan (sec. 4.1.12) and analyzed to determine basic feasibility (sec. 4.1.14).

4.1.2 Functional Requirements

4.1.2.1 The functional information about the system that must be obtained includes channel types (quantities and quality), terminal locations, direction of information flow, compatibility with existing equipment and services, and flexibility for expansion. Uncertainty in functional requirements often translate into additional system costs because increased flexibility must be designed into the system. Although flexibility is very desirable if it can be obtained at little cost, it is often very costly in available resources and can be obtained only at the expense of other valuable features.

4.1.2.2 Communication centers that are to be connected through the main trunk should be located as precisely as possible. Radio terminals that are to be serviced by spur links off the main trunk should also be located. The positions of radio terminals help to outline a large strip of terrain that is desirable for locating the main trunk. Information about the channel types, capacity, quality, quantities, and direction of flow is necessary for determining spectrum and power requirements.

4.1.2.3 Plans or possibilities for future system expansion should be examined. Appropriate planning for the initial system must include provisions for later upgrading or expansion so that site reconfiguration or new construction can be minimized. The designer should also consider future channel requirements in addition to current needs when specifying equipment. System upgrading may necessitate enlargement of buildings, greater air conditioning capacity, increased logistic capabilities, enlargement of the siting area, and possibly relocation of existing stations, or addition of new terminal or repeater sites.

4.1.3 Channel Parameters

4.1.3.1 Information on the number and quality of channels, required bandwidth, and direction of traffic flow is needed to determine frequency spectrum and power requirements. Such information for FDM-FM systems can be listed using the format in Worksheet 4.1-1 for each link. It provides also the basis for estimating spectrum requirements for the purpose of requesting frequency assignments (see sec. 4.1.10).

4.1.3.2 Nominal values given in Worksheet 4.1-1 may be used in lieu of more current information. The relation between the number of voice channels, per-channel deviation, and the total radio frequency spectrum requirements is shown in figure 4.1-1, and will also be discussed later on in section 4.5.5. The number of channels needed to carry traffic over each link will often be equal in both directions.

Current and future channel requirements for traffic

from site ______________ to site ______________.

Type of Channel	Number of Channels	Baseband per Channel	Quality	Equivalent voice channels per information channel	Number of equivalent voice channels	Baseband Spectrum
Voice (Telephone)						
Voice (Facsimile)						
Voice (Low Speed Data)						
Voice (Medium Speed Data)						
Digital Data (High Speed)						
Video						

Totals ________ ________

Link channel requirements rounded to the next higher nominal value [1] ________

Transmitter RF bandwidth[2] ________

(Future Expansion)

Voice (Telephone)						
Voice (Facsimile)						
Voice (low Speed Data)						
Voice (Medium Speed Data)						
Digital Data (High Speed)						
Video						

[1] Nominal values are 24, 60, 120, 300, 600, 960, and 1800.

[2] Estimate using figure 4.1-1.

Worksheet 4.1-1 Format for Recording Channel Requirements for FDM-FM Systems.

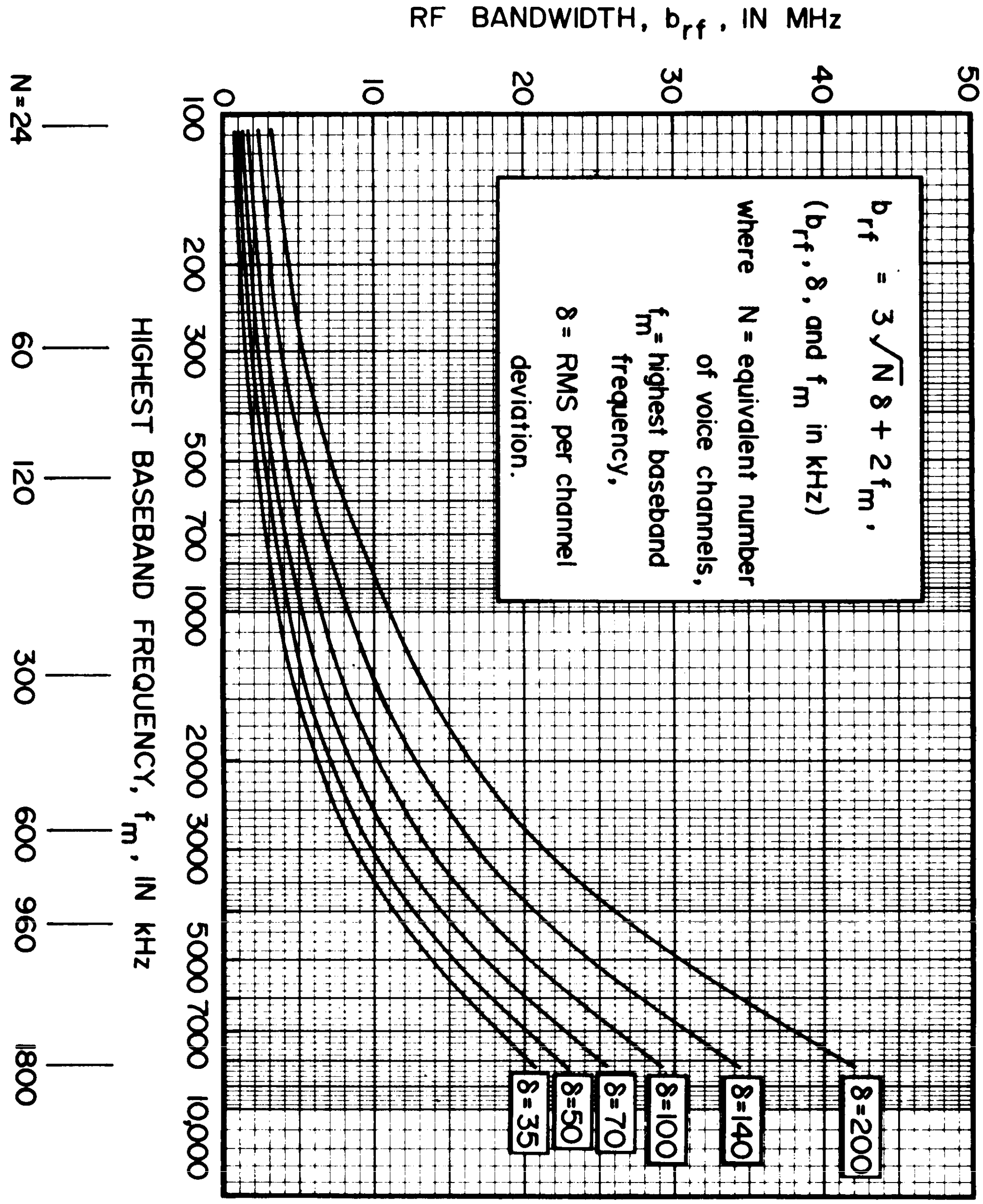


Figure 4.1-1 Dependence of Radio Frequency Bandwidth on Baseband Width for FDM-FM Systems

The total spectrum requirements may, however, be double the values determined here if it is necessary to employ frequency diversity. This may have to be considered when extremely long or otherwise difficult links are involved, but cannot really be determined until the procedures in section 4.2 have been followed through.

4.1.3.3 Similarly, transmitter power requirements must also await the results of preliminary design calculations. However, in the case of LOS systems the required transmitter power values will seldom exceed 10 watts, and this value may be used at least initially in the application for frequency assignment.

4.1.4 Resource Limitations

4.1.4.1 Resource limitations must be studied to determine costs and feasibility. These limitations include economic restraints, real estate availability, construction limitations, spectrum availability, socio-political considerations (especially in foreign countries), and time. Information (even for the initial input) should be as complete, comprehensive, and accurate as possible. Known major resource limitations should be compiled, and a list should also be made of potential major limitations for which the information resulting from initial surveys is inadequate. Systematic methods should be set up to seek and utilize additional information on resource limitations as system design proceeds.

4.1.5 Economic Restraints

4.1.5.1 The initial system cost estimates are important because requests for final project funding may be based on these estimates. The design engineer should keep cost estimates updated as the design proceeds, so that fiscal planners have sufficient time to modify funding requests, if need be. FM/FDM multiplexing equipment costs are nearly proportional to the number of channels over the path, whereas for a TDM system much of the circuitry is common and the terminal costs rise slowly as the channel requirement increases. Terminal costs for microwave equipment rise only slowly since much circuitry is common. The cost for diversity equipment, waveguide, towers, heating and air conditioning, etc. , are relatively fixed and will be similar at each site. Building costs may vary widely over the area covered by a specific system, and if construction must be speeded up to meet an operational deadline, the costs may escalate rapidly because of premium pay for overtime work.

4.1.6 Real Estate Availability

4.1.6.1 There are usually many factors limiting the number of suitable terminal and relay sites. Some of these factors are large bodies of water, blockage by terrain or terrain clutter (without using unacceptably high towers), prior use of suitable sites, political boundaries, potential interference with other radio systems, local zoning regulations ease of access, and environmental aspects. Site availability investigations should include a check into possible site security problems. Particularly, unattended operation increases the possibility of theft, vandalism, or other damage and may require special and substantial considerations. Site development costs will generally be subs tantially lower if a site can be found on government-owned lands, rather than on private property.

4.1.7 Construction Limitation

4.1.7.1 The most common and important construction limitation is that of tower height. Towers exceeding a given height may violate local ordinances for a number of reasons. If a link will be near an airport, or in established air corridors, the site proposed may not be approved if it requires the use of high towers. Similar restrictions may be encountered in or near residential areas, or in certain scenic areas. A very remote site may involve special construction restrictions if access roads will not permit heavy equipment (e. g., cranes) to reach the site. Certain types of construction materials may be unavailable or unduly expensive in some areas, and special types of construction may be necessary because of local climatic conditions, as in the arctic, or extremely wet regions, or in regions subject to earthquakes.

4.1.8 Primary Power Limitations

4.1.8.1 Definite information on the availability of commercial electric power will probably have to await the results of site surveys. Initially, it will be sufficient to determine from available reference sources or contacts in the area of the proposed system whether or not such power is likely to be available. If power for a site must be provided by engine-generator sets, the problem of hauling fuel to the site must be considered, as well as the additional expense involved for buildings, equipment, fuel storage and even operating personnel if the equipment cannot be automated. The principal power requirements for LOS systems will come from heating and cooling demands since transmitter power is usually quite low.

4.1.9 Frequency Spectrum Availability

4.1.9.1 The designer should work through the applicable Frequency Allocation Office to determine what blocks of frequencies can be made available for the proposed system. Despite the lack of specific information on system parameters and routing, it is important that early contact be made with this office, since at least a preliminary commitment must be available prior to the feasibility study. The designer should assemble as much information on the proposed system as possible prior to this initial contact, e. g., the geographical area involved, approximate locations of terminals or installations to be served, and probable RF power and bandwidth requirements. At least general information on the size of antennas and type of terminal equipment will probably also be available at this time. Further information on the type of information generally required for frequency allocations is given in paragraph 4.1.11.1, but the exact format for a particular case should be obtained from the Frequency Allocation Office. For extensive systems, more than one nation may be involved in the frequency allocation negotiations. This can result in considerable delay in obtaining the desired assignment, so it is very important that the system designer work closely with the Frequency Allocation Office from the beginning of the design effort.

4.1.10 Radio Frequency Assignment

4.1.10.1 Frequency assignments are made through negotiations with the frequency-controlling agencies of the countries where the system is to be installed. These negotiations are conducted by the Military Communications-Electronics Board (MCEB) of the Department of Defense. In carrying out these negotiations, the MCEB utilizes the services of portions of certain agencies established for this purpose: the Frequency Allocation Panel, U.S. (FAPUS); the Frequency Division of the Defense Communications System Directorate; the Communications -Electronics Directorate of the Joint Chiefs of Staff (J-6); and the Frequency Branches of the Communications-Electronics Divisions of the Unified Commands. The system engineering function in this process is to provide the necessary technical inputs for the negotiations.

4.1.11 Application for Frequency Allocation

4.1.11.1 Table 4.1-1 contains a list of items usually specified in applications for a frequency allocation. Each item of the list that is pertinent to LOS system planning should be included in the application if known. (This information was adapted from pp. 4-172 to 4-175 of [2]).

4.1.12 Engineering Implementation Plan (EIP) Contents and Organization.

4.1.12.1 The EIP is a compiled report of all factors that contribute toward the development of the microwave radio system, from the initial proposal to the final system acceptance. It is recommended that the EIP be started as soon as information on functional requirements and resource limitations become known, and will consist of notes, letters, maps, tables, profiles and sketches, etc. The EIP will be primarily an organization of known data, and its first use will contribute toward the completeness and insure the availability of information necessary for the determinations that must be made during the feasibility study. It must be complete and its contents kept timely, since it will continually be used as a basis for decision and proposal implementation.

4.1.12.2 All system design data that are developed and used for decisions should be placed into the EIP. For purposes of determining required content and organization, it is recommended that the EIP be organized in accordance with the worksheets supplied in Chapter 6. This organization separates the EIP material according to individual sites and links. Because some material is applicable to both sites and links, appropriate cross referencing should be used. Material which is applicable to the whole system, such as system layout and frequency

Table 4.1-1 Data for Frequency-Allocation Application

No.	Item	Comments
	Proposed Allocation	
1	Frequency band	Enter the frequency limits between which it is technically feasible to operate the equipment in performance of its required function.
2	Function	Describe the function to be performed by the equipment as specifically as possible; i.e., multi-channel communications.
3	Purpose and method of operation	Describe the purpose and method of operation; i.e., to provide within-the-horizon transmission by line-of-sight propagation.
4	Geographical area	State geographical area or points of use actually required under joint and service plans: Give geographical coordinates or terminal locations where known.
5	Extent of use	A narrative statement describing the number of equipments and/or systems normally utilized in a given area of operation. The number is the number of terminals in the system. They are to be operated continuously.
6	Degree of protection required	List any special considerations with respect to interference vulnerability, special features incorporated, or techniques employed which make the equipment less susceptible to interference from other equipments. Give receiver tuned cavity filter characteristics.
7	Target date for operations	Indicate the date on which it is expected that operational use of the equipment or system will occur.
8	Previous allocation and/or equipment to be changed or superseded	Identify the allocation and/or equipment affected and describe the change or supersession.
	Transmitter	
9	Nomenclature of transmitter of system	List joint nomenclature if available, i.e., AN/GRC-66, or manufacturer's identification. If no nomenclature has been assigned state "NONE".

Table 4.1-1 (Continued)

	Transmitter	
10	Installation	Indicate type of ship, vehicle, weapon, aircraft, missile, or place where installed and whether fixed or transportable; e.g., U.S. Army post; fixed, ground installation.
11	Actual tuning range and/or operating frequencies	Indicate maximum tuning range for satisfactory operation and/or specific stop frequencies which can be employed, and optimum operating frequencies: All optimum operating frequencies should be stated.
12	Type emission	List type of emission. For line-of-sight FDM-FM systems, this will be F3.
13	Bandwidth	List the necessary bandwidth for communication. For DCS line-of-sight systems, the modulation type will usually be frequency modulation and the necessary bandwidth can be estimated from figure 4.1-1, as described in section 4.1.3.
14	Pulse repetition	Applicable only to pulse modulation systems.
15	Pulse width	Applicable only to pulse modulation systems.
16	Modulation and coding	Indicate type of modulation, if any, and give general description of any coding system. For DCS line-of-sight FDM-FM systems, list "FM with single-sideband suppressed carrier, frequency-division multiplexing."
17	Power output	State power output to the antenna in watts and whether it is average, peak, or root mean square.
18	Frequency control	Indicate means for obtaining frequency control.
19	Stability	Indicate frequency stability of transmitter under normal operating conditions. Minimum stability for DCS systems is given in [98], para. 3.2.2.5.4.4.2.3.

Table 4.1-1 (Continued)

No.	Item	Comments
20	Antenna	a. Indicate type antenna, e.g., horn-feed with parabolic reflector. b. Indicate whether antenna is fixed, directional or scans horizontally or vertically and rate of scan. For line-of-sight, the antenna is usually fixed and directional. c. State the antenna gain in dB relative to isotropic. d. State the beamwidth, horizontal and vertical angles in degrees at half-power points, e.g., horizontal 0.7°, vertical 0.7°.
21	Status of development	Indicate present status of proposed equipment or system.
22	Target date for operational availability	Indicate target date of availability for operational use.
	Receiver	
23	Nomenclature	List joint, manufacturer's, or other applicable nomenclature, e.g., AN/GRC-66.
24	Installation	State whether installation is integral with transmitter, if not, give installation data as fixed, portable, missile, etc. In DCS line-of-sight, the receiver installation is usually integral with the transmitter installation.
25	Actual tuning range and/or operating frequencies	Indicate actual frequency range or specific frequencies over which receiver can operate successfully.
26	IF frequency	Indicate frequency of "IF" amplifier. [98], para. 3.2.2.5.4.4.4 states that the IF center frequency shall be 70 MHz
27	Selectivity	List the overall bandwidths of the receiver at 3, 20 and 60 dB points on selectivity curve. Use $B_{IF} = 2(\Delta F + f_m)$, where B_{IF} is the IF bandwidth, and usually identical to the radio frequency bandwidth determined from figure 4.1-1 for the 3 dB points.

Table 4.1-1 (Continued)

	Receiver	
28	Sensitivity	State the minimum signal level in microvolts or dBm required for acceptable or standard output signal from manufacturer's specifications. Indicate the noise figure of the receiver in dB (also from manufacturer's specifications). For operational allocation, state the minimum ratio of desired signal to undesired signal necessary for operation of the system. This ratio should be at least 60 dB.
29	Stability	Indicate receiver frequency stability under normal operating conditions. Minimum stability for DCS systems is given in [98], para. 3.2.2.5.4.4.4.1.
30	RF Preselection	State whether RF preselection is employed, and type of preselection used, e.g., tuned cavities.
31	Frequency range of local oscillator	Where local oscillator is tunable, give frequency range. As this will vary from manufacturer to manufacturer, this information will have to be obtained from the manufacturer's specification.
32	Antenna	a. Indicate whether antenna is same as for transmitter. For line-of-sight systems, it is. b. State antenna gain in relation to isotropic. c. Beamwidth in degrees for azimuth and vertical, e.g. horizontal 0.7°, vertical 0.7°.
33	Status of development	Indicate present status of proposed equipment or system. This should be the same statement as for the transmitters.
34	Target date for operational availability	Indicate the expected target date when the equipment will be available for operational use. This date should coincide with the target date for operational availability of the transmitters.
35	Remarks	Add any information believed to be of assistance in evaluating the circumstances under which the proposed system or equipment will be operated. At a minimum, this should include reference to current DCA standards.

plans, must be separated according to individual categories. For example, all discussions, letters, etc. , pertaining to the availability of frequency spectrum would be placed in the system EIP under "Frequency Planning."

4.1.12.3 Original material should be placed in the EIP as soon as it is available, and reproduced copies made for discussion or transfer to other parties. This will soon become quite large, but the designer is cautioned to save all contributing data and insure that they are properly cataloged. It may also be desirable to prepare a smaller, edited system plan that summarizes the design effort and gives only those details which are of primary importance.

4.3.13 EIP Deadlines and Schedules .

4.1.13.1 Requirements for the design of a system will usually include one or more deadlines for the completion of various tasks. Deadlines will have to be considered when planning for procurement of construction materials, scheduling employment of personnel, and establishing lead time necessary for sub-contracting, equipment procurement, and related efforts. To insure that planning objectives are realistic, a table of events for the project should be prepared and made available for early review. This scheduling may be prepared using a flow chart or a simple scheduling chart such as the one shown on table 4.1-2, which is based on one calendar year. More details in scheduling will be required as the design progresses.

4.1.14 Determine Basic Feasibility

4.1.14.1 During the design phase there are usually two times when the feasibility of the proposed system may be evaluated. The first is after completion of the survey of functional requirements and resource limitations. Final feasibility evaluation should be made prior to

Table 4.1-2 LOS Microwave Engineering Implementation Plan Schedule

SCHEDULE SUMMARY	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Desk Study												
First Site Survey												
Route and Site Selection Review												
Link Design												
Final Site Survey												
System Analysis												
Equipment Specification Preparation												
Preparation of Final Cost Estimates												

actual site and equipment purchase. This is possible after detailed studies of expected system performance based on field surveys where necessary, and of accurate cost data for preparing each site. However, the design engineer must continuously verify that the limitations previously investigated with regard to resources do not impose insurmountable barriers.

4.1.15 Review Requirements vs. Limitations

4.1.15.1 The engineer should review the information gathered to insure its completeness so that appropriate authority may later view and determine the soundness of the system proposal. Based on information received, there may be problems and questions requiring solutions before a decision to continue or not can be made. The design engineer must also be aware of available alternatives to the design plan. For instance, if existing LOS links can be incorporated into the design through upgrading and still fulfill the system requirements, such a recommendation should be made to the reviewing authority. Finally, all data for use in determining feasibility should be duplicated for dissemination to insure that persons involved with the system keep informed on the current status.

Section 4.2 STUDY OF ROUTE ALTERNATIVES.

4.2.1 General

4.2.1.1 If the preliminary assessment of the proposed microwave system indicates that its requirements might be met within the limitations imposed, a study should be started directed toward selection of routes and sites.

4.2.1.2 This selection study requires the choosing of preliminary sites and routes. Drawing profiles and making rough estimates of path loss probability distributions for each link will help eliminate potentially troublesome links. This information, along with additional input such as meteorological data, propagation information from other links in the immediate area, area radio interference data, etc., should be evaluated to make a firm selection of primary and alternate routes, with their associated site locations. For additional information on the organization of section 4.2, see figure 1-2.

4.2.2 Select Potential Sites

4.2.2.1 Site selection will initially be made considering the use of available areas and choosing sites on the basis of information obtainable from topographic maps. Additional aspects of site choice such as site function (terminal, branch, relay), accessibility and power availability must also be considered.

4.2.3 Eliminate Non-available Areas

4.2.3.1 Information on real estate availability, gathered for the feasibility study described in section 4.1, can now be used to eliminate, or downgrade, some of the potential site locations. Political, security, and economic considerations may eliminate large areas from consideration. On a system layout map, these areas may be shaded and labeled to designate the reasons for elimination from consideration, or the downgrading of their desirability, as site locations. Obviously such designations allow attention to be systematically focused on sites in areas of greatest potential.

4.2.4 Obtain Best Available Maps

4.2.4.1 The maps obtained for site selection studies should be current. Often maps which have been used on previous studies are out-of-date and do not show such things as recent man-made lakes, new construction, timber removal, road improvements, etc. Several map scales should be obtained. Small maps showing the whole area are useful for system planning and layout work, while maps showing greater detail should be used to plot site locations and provide data for path profiles.

4.2.4.2 In the preliminary selection of routes and sites the path profiles should be drawn using reliable contour maps. For areas within the U.S. these maps are available through the U.S. Geological Survey and the U.S. Coast and Geodetic Survey. Additionally, maps may be obtained through the Corps of Engineers, U. S. Army Map Service, U.S. Hydrographic Office, or the U.S. Forest Service. Maps of foreign areas are published by the U.S. Air Force Aeronautical Chart and Information Center and sold by the U.S. Coast and Geodetic Survey, or they may be obtained through the U.S. Army Map Service. Foreign area maps may also be requested through appropriate U.S. Embassy sources, or purchased locally.

4.2.4.3 The maps made by some nations do not use the prime meridian that passes through Greenwich, England. Table 4.2-1 shows some of the other prime meridians which may be used. Due consideration must be given to the difference between the Greenwich prime meridian and the one used on the map when locating sites.

Greenwich longitude of foreign prime meridians
(Values used by Dept. of Geodesy, Army Map Service)

Meridian	Accepted Longitude (Based on Greenwich Meridian)
Paris, France - - - - - - - - - - - - - -	2° 20' 13.95″ E
Madrid, Spain - - - - - - - - - - - - - -	3° 41' 14.55″ W
Monte Mario, Rome, Italy - - - - - -	12° 27' 07.06″ E
Sumatra, Netherlands East Indies - - -	103° 33' 27.79″ E
Ferro, Canary Islands - - - - - - - - - -	17° 39' 46″ E (17° 40' 00″ E used by Germans)
Amsterdam, Netherlands - - - - - - - -	4° 53' 05.45″ E
Lisbon (observatory of Castelo de S. Jorge), Portugal - - - -	9°07' 54.806″ W
Naval Observatory at Genoa, Italy - - -	8° 55' 15.929″ E
Copenhagen, Denmark - - - - - - - - - -	12° 34' 40.35″ E
Athens, Greece - - - - - - - - - - - - -	23° 42' 58. 5″ E
Helsinki, Finland - - - - - - - - - - -	24° 57' 16.5″ E
Pulkovo (near Leningrad), U.S.S.R. - -	30° 19' 38.49″ E
San Fernando, Spain - - - - - - - - - -	6° 12' 17.43″ W
Singkawang, Borneo - - - - - - - - - - -	108° 59' 41″ E
Istanbul, Turkey - - - - - - - - - - - -	28° 58' 45.5″ E

Table 4.2-1 Table of Prime Meridians

4.2.4.4 For preliminary feasibility studies, a topographic map having a scale of 1:250,000 should have sufficient detail, although the design engineer should use the best available maps when more detailed analysis is required. When requesting maps of the areas, the following approximate scales should be specified: 1:250,000, 1:50,000 and 1:25,000. As site locations become fixed, contour maps with larger scales, if available, should be requested for the site areas and critical portions of the path. Additionally, these maps should show vegetation and man-made objects.

4.2.4.5 Useful information on an area may be obtained from aerial photographs. These photographs are normally current and show trees, buildings, roads, etc. , in very good detail. There is no central office from which reproductions of all aerial photography can be purchased; however, from a status map supplied by the Map Information Office, U. S. Geological Survey, Washington, D. C. 20242, a determination may be made of who holds the film for certain areas. If it is a Federal government agency, they may be contacted directly. If the film is held by a commercial firm, contact the Map Information Office for the procedures for obtaining copies.

4. 2.5 Preliminary Site Selection

4. 2.5.1 Communication centers are specified in the information required for the initial feasibility study. A line-of-sight microwave system usually has the conformation of a main-line trunk between communication centers with spur links to users along or off the main trunk. The locations of the large communication centers are usually determined by factors unrelated to microwave system design, and the final connection between the main-trunk microwave system and a communication center is also often made with a short spur link or coaxial cable.

4. 2.5.2 Radio terminal sites should, if possible, be located on elevated ground close to the communication centers. This makes the use of lower tower heights possible and allows, at the same time, convenient connection to the switching facility interfacing with the micro-wave radio system.

4.2.5.3 After radio terminal sites have been designated, potential branching sites are determined. In some cases, a terminal may also be a branching site. The branching sites particularly should be located on elevated ground since co-visibility will be required with three or more sites.

4.2.5.4 Because of the high probability of continuous manpower requirements at terminal and branching sites, the accessibility of each site must be investigated and should include a survey of the availability, or usefulness of present or planned roads, railroads, air, and/or water transportation. Each type of accessibility will later require a more detailed investigation; such as, for roads: road surface, grade of roadway, load and clearance limits of bridges, and climate conditions that might affect the road use. When a number of site choices are available, consideration should be given first to sites located near existing roadways and commercial primary power.

4.2.5.5 The last sites to be selected are the repeater sites used to receive and forward communications without change of their contents. Repeaters may be either active or passive. These sites are sometimes located in areas where transportation for logistic and maintenance requirements must be provided by means of helicopters or equipment designed for deep snow transportation. Primary power for active repeaters, in remote areas may be very costly, and is therefore an important consideration in the selection of repeater sites.

4.2.6 <u>Select Potential Routes</u>

4.2.6.1 Having selected potential sites in a wide belt of terrain connecting the communication centers, a set of potential routes may be chosen. Those sites considered exclusively as repeater sites should be ignored for the most part during the initial route selections since preliminary selection will eliminate many routes.

4.2.6.2 At frequencies above about 8 GHz, rain attenuation becomes a serious problem, and usable path lengths are quite short if severe outages due to rain are to be avoided. Figure 4.2-1 (which will be discussed in more detail in section 4.2.24) shows, as an example, that the nominal path length at 15 GHz should be restricted to about 4 km in areas where intense rainstorms are frequent (Zone 6) . Since storm cells with heavy rain rates are relatively small in diameter (on the order of kilometers), a system of parallel routes about 5 to 10 km apart provides some protection against outages and permits longer links on the individual routes. However, the relative advantages of a route diversity over a purely tandem system depend on several additional considerations such as:

a. Phase interference fading is often related to path length.

b. Locations where the routes bend or combine are still vulnerable to the effects of storm cells.

c. The reliability improvement is a function of the lateral separation of paths, d_s, but quantitative values have not been well established. The ratio of allowable path lengths for dual parallel diversity to that for tandem paths will probably be 4 or larger in many areas for frequencies above 18 GHz and $d_s > 10$ km (see [16]; p. 2960).

d. Because of the different number of individual links involved, frequency requirements will differ.

e. Dual route diversity also provides equipment redundancy in addition to propagation reliability. Also, links of an individual route can be taken out of service for testing or maintenance without disruption of service.

4.2.7 Choose Potential Relay Links

4.2.7.1 Nominal LOS path length, d_n between various branch, terminal and repeater sites will vary with the climatological condition in any particular area. Figure 4.2-1 is a graph showing recommended nominal path length as a function of frequency and the rain-rate zones shown in figures 4.2-11 and 4.2-13. For $d_n < 40$ km, the curves are based on the probability of having rain attenuation fades exceeding 40 decibels during less than 0.001 percent of the time, and assuming that the maximum average rain-rate will occur simultaneously over 10 kilometers or the entire link, whichever is less. Thus, the values of d_n may be used as a guide for spacing repeaters so that a desirable grade of service with an acceptable time availability can be maintained using a normal range of RF power levels and antenna gains. For conditions not covered in figure 4.2-1, a value of d_n of 40 km should be used. For example, up to 8 GHz in zone 6, $d_n = 40$ km; however, in zone 1, $d_n = 40$ km may be used up to 23 GHz. The limiting 40 km value of d_n is based on fading caused by mechanisms other than rain attenuation. The reliability required for backbone routes performing to DCA Standards might be achieved with links 40 km or longer even in zone 6 if route diversity is used.

4.2.8 Choose Direct Routes

4.2.8.1 Direct routes between branch sites and terminals will generally tend to minimize the number of active repeater stations between terminals; however, repeater stations may be intentionally located along a zig-zag path to avoid self-interference within a system in areas where stratified air layers sometimes guide radio waves well beyond the optical line-of-sight, and where frequencies must be reused.

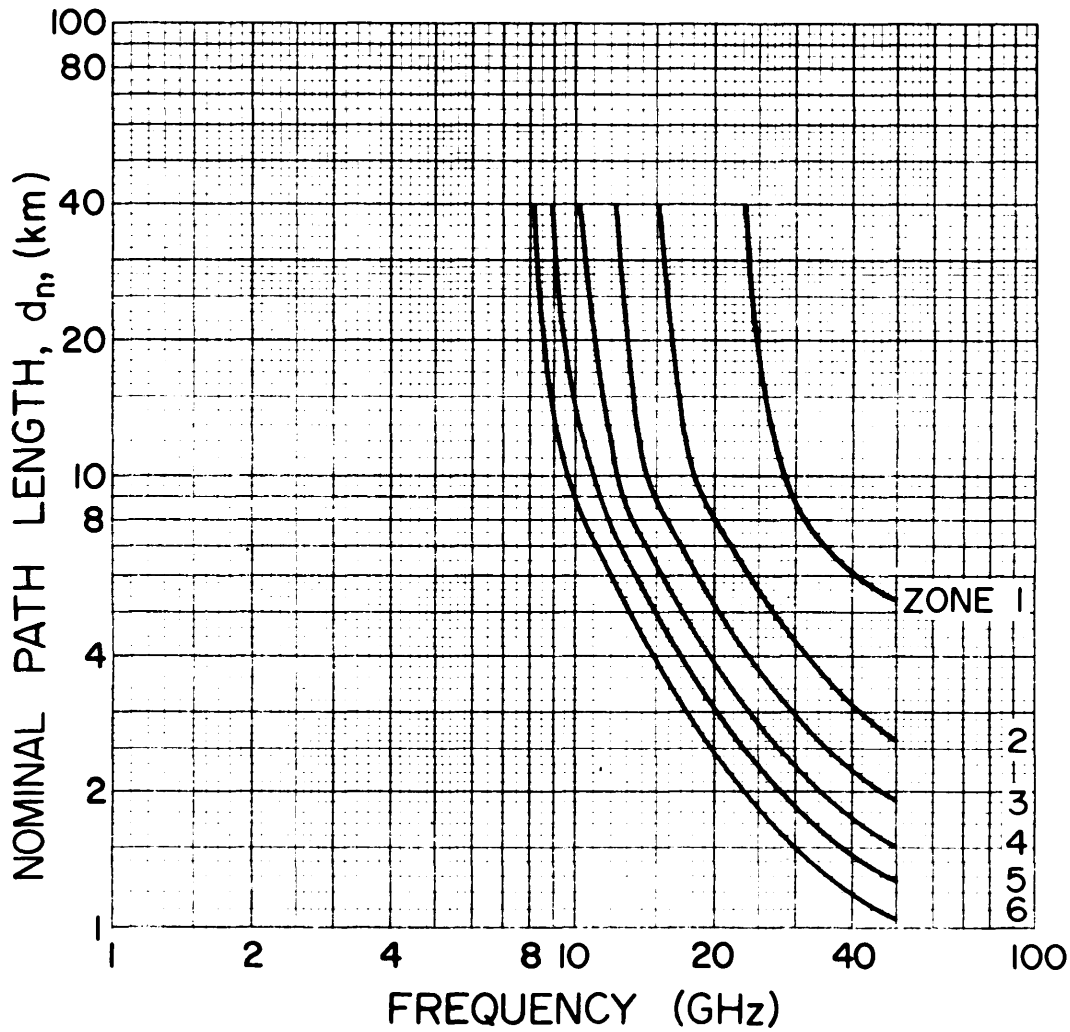


Figure 4.2-1 Nominal Path Lengths for Line-of-Sight Paths between 8 and 40 GHz without Parallel Route Diversity

4.2.9 Consider Passive Repeaters

4.2.9.1 Passive repeaters are usually reflectors on hills adjacent to a terminal. They are illuminated by an antenna on a short structure at the terminal, and serve to provide the required terrain clearance where this is not possible directly between terminals. They are also useful in rough terrain where shorter paths are required to obtain the necessary line-of-sight clearance, and can often replace an active repeater site.

4.2.9.2 Passive repeaters offer many economic and technical advantages. Access problems are less important for a passive repeater site than for an active repeater site since no primary power source and little, if any, maintenance is required. Capital investment is also less than for an active repeater but these savings may be partially countered by increased power or antenna gain requirements at the active terminals of the link. Primary advantages of passive repeater links are that equipment requiring maintenance and logistic support can often be placed in valleys for easy access and flexibility of location, and the angle of penetration through the atmosphere to the passive repeater on a nearby hill or mountain may be large enough to minimize multipath fading (section 4.2.11).

4.2.9.3 Transmission loss for passive repeater paths will be lowest when one leg of the path is much shorter than the other. The loss in decibels, L_p, between antenna terminals at the opposite ends of a link using a passive repeater may be approximately calculated as the sum of the basic free-space transmission loss values for the two legs less the sum of all antenna gains. The free-space loss, L_{bf}, is given by [8] page 2-7:

$$L_{bf} = 32.45 + 20 \log f + 20 \log d \text{ dB} \qquad (4.2\text{-}1)$$

where d is in km and f is in MHz. (see also section 4.2.21).

Then,

$$L_p = 32.45 + 20 \log f + 20 \log d_1 + 32.45 + 20 \log f + 20 \log d_2 - G_1 - G_2 - 2G_p \text{ dB} \qquad (4.2\text{-}2)$$

where G_1 is the gain of the antenna at site 1, G_2 the gain at site 2, and G_p is the gain of the aperture of the passive repeater projected perpendicular to the propagation path. All gains are in dB relative to an isotropic radiator, and the distances d_1 and d_2 in km are defined in figure 4.2-2.

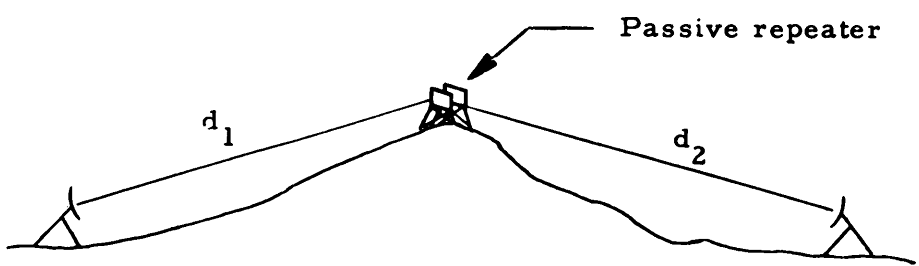


Figure 4.2-2 Typical Passive Repeater Configuration

The formula for L_p may be rewritten as follows:

$$L_p = 64.9 + 40 \log f + 20 \log d_1 d_2 - G_1 - G_2 - 2G_p. \qquad (4.2\text{-}3)$$

4.2.10 Consider the Number of Sites

4.2.10.1 Routes where the number of required sites is substantially greater than that for other plausible routes may be eliminated since the additional sites decrease system reliability and generally result in increased costs.

4.2.11 Atmospheric Layer Penetration

4.2.11.1 A layer in the troposphere in which the atmospheric refraction differs considerably from the refraction in adjacent layers may cause sufficient bending of a radio beam to produce multipath or phase interference fading. This bending may be comparable to reflection when the angle of incidence of the beam at such a layer is less than about 0.5°, but at angles above 3° the effect is negligible. This angle of incidence is sometimes referred to as the <u>penetration angle</u>. Unfortunately, conditions conducive to atmospheric stratification often exist over flat terrain where large penetration angles cannot be obtained without excessively towers [3, page 61; 45, page 146]. Refractive structure of the lower atmosphere is discussed in detail in Section 4.4.6.

4.2.11.2 If the take-off-angle of the antenna beam at the lowest site above mean sea level (msl) is positive, it is the smallest angle of penetration along the path. If the take-off-angle at the lowest site is negative, the angle of penetration will be zero at some location along the path.

4.2.11.3 The take-off-angle, β, is the angle between a horizontal line extending from the center of an antenna and a line extending from the same point to the other terminal antenna.

$$\beta \approx \frac{\left(h_2 - \frac{d^2}{2a}\right) - h_1}{0.0175\, d} \text{ degrees} \qquad (4.2\text{-}4)$$

where all distances and heights must be in the same units.

h_1 is the height of the lowest antenna above ms1.

h_2 is the height of the other antenna.

d is the path length.

a is the effective earth radius.

4.2.12 <u>Select Preliminary Routes</u>

4.2.12.1 After careful study of topographic maps and considering the other factors mentioned, the design engineer should choose a number of possible routes that warrant further investigation. A typical difficulty is that links selected for minimum fading potential or tower heights will involve locating the sites in a remote area. Low levels of man-made noise will also be obtained by locating sites in a remote area; but this may result in poor site accessibility. Absolute guides for selection cannot be given and the design engineer will have to weigh the various considerations applicable to each path and make his preliminary route selection on that basis.

4.2.13 Drawing Initial Terrain Profiles

4.2.13.1 Terrain profiles are prepared to verify that the selected routes and sites are reasonable possibilities for LOS paths.

4.2.14 Map Scale

4.4.14.1 Even though the number of site and route possibilities being considered at this point in the route selection involves many paths, the most detailed maps available should be used for drawing the initial path profiles. The quality and scale of maps for various areas will be diverse; thus, uncertainty about some paths with marginal clearance may only be resolved by the field survey.

4.2.14.2 Most large-scale and medium-scale maps have, in addition to longitude and latitude coordinates, a grid system for locating or referencing points. This grid system is identified as the Universal Transverse Mercator (UTM) grid and is designed for world use between 80 degrees south latitude and 84 degrees north latitude. A detailed explanation of the UTM grid and its application to military use is given in [11] (pages 17 to 25); however, a brief general review is presented here.

4.2.14.3 The military grid reference consists of a group of letters and numbers which indicate (1) grid zone designation, (2) the 100,000 meter (100 km) square identification, and (3) the grid coordinates of the point expressed to the needed accuracy.

4.2.14.4 The UTM grid divides the world into large, geographic areas (6 degrees E-W by 8 degrees N-S except that the region 72 degrees to 84 degrees N constitutes one area) which are designated as the grid zones. The columns are numbered 1 to 60 consecutively and the rows identified by letters alphabetically C through X (I and O omitted). The grid zone designation of any area is determined by first reading the column designation and then the row designation (see figure 4.2-3).

4.2.14.5 Each grid zone is then divided into 100,000 m squares. Each column of squares is identified by a letter, as is each row of squares. Starting at the 180 degree meridian and proceeding easterly along the equator for 18 degrees, the 100,000 m columns, including partial columns along grid junctions, are lettered A through Z (omitting the letters I and O), and are repeated at 18 degree intervals. The 100,000 m rows are lettered A through V (1 and O omitted) from south to north. This partial alphabet for rows is repeated every 2,000,000 m. Thus the identification of any 100,000 m square consists of two letters, the first determined by reading horizontally and the second vertically.

4.2.14.6 The grid coordinates of a point within the grid square can be expressed as precisely as desired, and are written as one number always containing an even number of digits. The first half of the total number of digits are read horizontally and the second half of the digits vertically. The measurement used with a grid system is linear and the unit of measure is usually the meter.

4.2.14.7 Example of a point identification within a UTM grid using a military reference:

10S locates the grid zone designation
10SGF locates the 100,000 m square
10 SGF65 locates within 10,000 m square

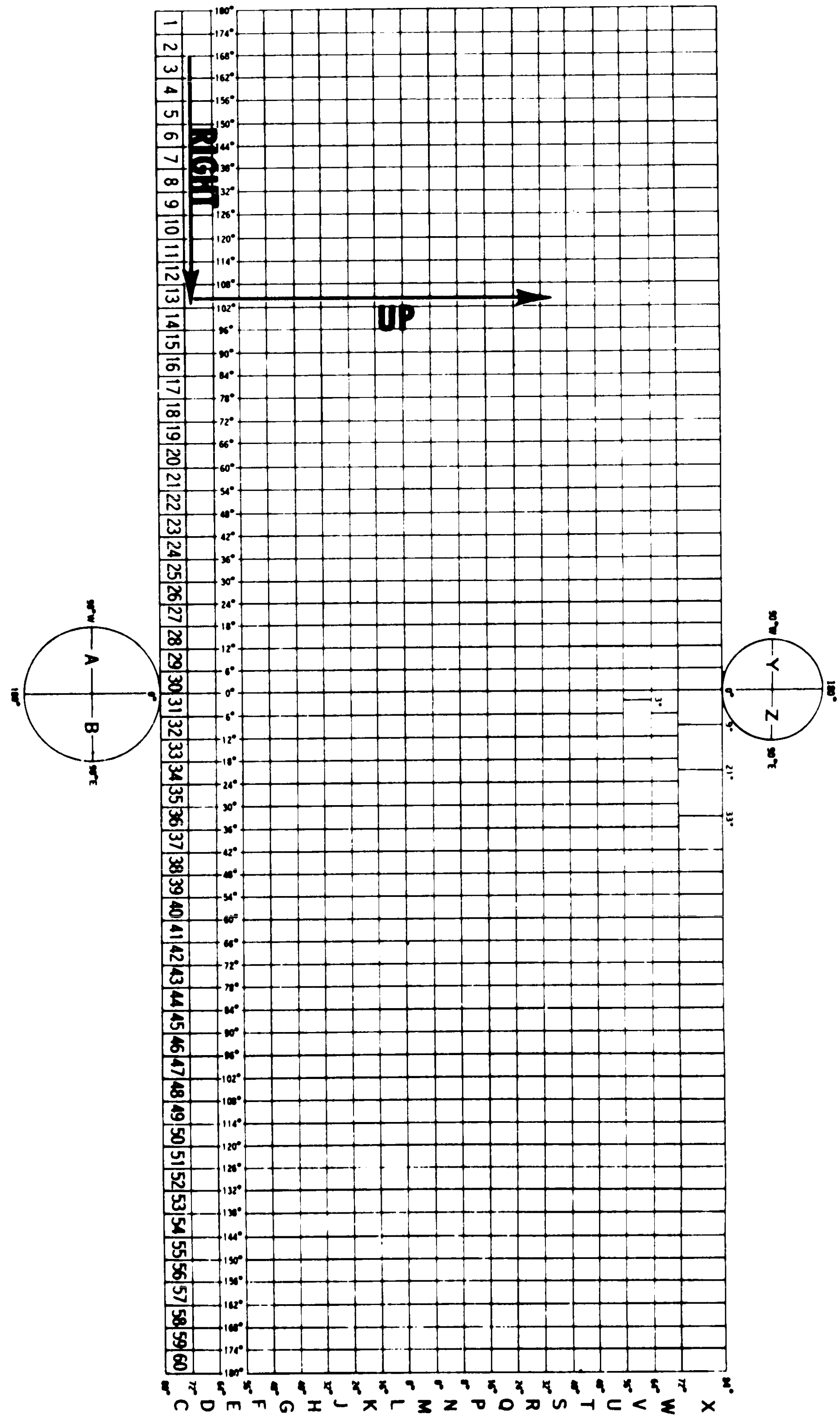


Figure 4.2-3 **Grid Zone Designation for the World**

10SGF6558 locates within 1,000 m square
10SGF654576 locates within 100 m square
10SGF65415758 locates within 10 m square

4.2.15 Initial Path Profile Drawings

4.2.15.1 Correct site selection is based primarily on accurate path profile determinations. These profiles normally show the longitudinal center of the radio beam and a cross-section of the terrain along a microwave path. For paths longer than 20 km, profiles should be plotted along the great circle path between sites. Hills and ridges near the great circle path must be taken into consideration, as well as the terrain on the beam centerline. Critical points along the profile should be plotted using the highest point on the horizontal arc defined by ±0.5 degrees from the great circle path where the nearest site is used as the vertex of the angle. Formulas for determining the great circle path across maps are provided in section 4.2.16. A radio ray in the vertical plane travels in a curved line which generally has a radius of curvature greater than the true earth's radius because of atmospheric refraction. Refractive effects can generally be expressed as changes in the effective earth's radius (see section 4.4.6 for additional information on effective earth's radius). Also, the effective earth's radius concept [17] and its derivation is treated in detail in Volume I of [8]. For the purpose of determining required terrain clearance and antenna heights, the ratio k of the effective to the actual (physical) earth radius (a_0 = 6370 km) is used. Useful values of k for initial design assumptions are infinity (corresponding to ducting conditions), 4/3 (corresponding to a "standard atmosphere"), 1 and 2/3 (corresponding to "sub-refractive" conditions which are very unfavorable for line-of-sight links).

4.2.15.2 The relationships between the microwave radio path and the elevation profile are commonly presented by either of two methods. One method is to prepare curvilinear graph sheets whose curvature corresponds to the applicable k-factor. On this paper, the radio beam axis is presented as a straight line. This method has often been used in the past, but has disadvantages because of limitations in the choice of scale and in the somewhat restricted choice of k-factors on generally available graph sheets. Alternatively, special graph sheets must be prepared for each required value of k. The second method, particularly recommended for LOS paths, is to plot the terrain elevations as a function of path distance on linear graph paper. Here, any convenient vertical and horizontal scales can be used, and the profile may usually be plotted on 8-1/2 x 11 inch paper. For such a plot, a straight line beam axis represents an effective earth radius equal to "infinity". Beam axes representative of other k values can then be plotted as curved lines with the points as displacements below the line representing $k = \infty$. These values of displacement, h, are calculated using either of the following equations:

$$h = \frac{d_1 d_2}{12.75\ k} \qquad (4.2\text{-}5)$$

or

$$h = \frac{d_1 d_2}{2a \times 10^{-3}} \qquad (4.2\text{-}6)$$

where h is in meters, d_1 and d_2 are distances from a point along the path to each terminal and are in kilometers, the effective earth's radius, a, is in kilometers, and k is the non-dimensional effective earth's radius factor. Figure 4.2-4 is a typical example of a profile plotted using this method.

4.2.15.3 All maximum elevation points on the profile should be carefully checked and symbols for trees or other vegetation used if the maps

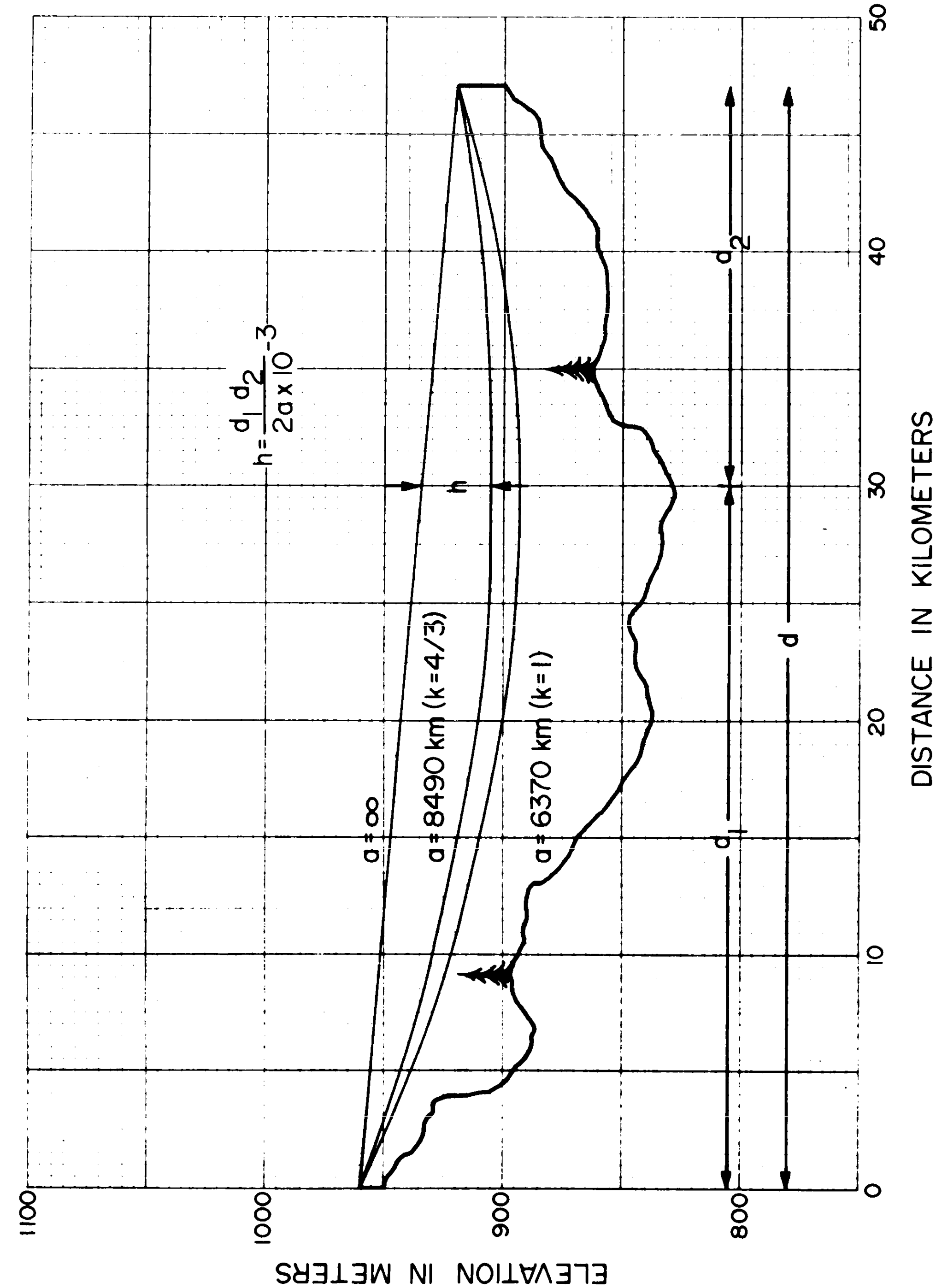


Figure 4.2-4 Typical Flat Earth Path Profile

indicate their presence. Vegetation, unless very sparse, at microwave frequencies is almost impenetrable to radio frequency energy, and should be added to the profile elevations so that the top of the vegetation can be used in evaluating terrain clearance. Similarly, if large buildings or clusters of man-made objects are present in the path they should be drawn on the path profile at their actual height.

4.2.15.4 A line-of-sight path that clearly has no obstructions to the radio beam is an excellent candidate for the system; however, paths having obstructions that make the path marginal (especially those for $k \leq 2/3$) should not be dismissed, but marked for further investigation until other aspects of the system are investigated. Marginal paths may often be made line-of-sight by increase in tower height at one or both ends of the path.

4.2.16 Plotting a Great Circle Path

4.2.16.1 The spherical triangle used for the computation of points on a great circle path is identified on figure 4.2-5 as PAB. A and B are the antenna terminals, and P the north or south pole. B is selected to have a greater latitude than A, and P is in the same hemisphere. The triangle shown is for the northern hemisphere but may readily be inverted to apply to the southern hemisphere. B' is any point along the great circle path from A to B, and the triangle PAB' is the one actually solved. The latitudes of the points are denoted by ϕ_A, ϕ_B, and $\phi_{B'}$, while C and C' are the differences in longitude between A and B and A and B', respectively. Z and Z' are the corresponding great circle path lengths. The following formulas are practical for hand computations as well as for digital computers. Equations 4.2-7 to 4.2-10 have been taken from [1] (pp. 26-9 to 26-11).

4.2.16.2 The initial bearings or azimuth values (Xfrom terminal A, and Y from terminal B) are measured from true north, and are calculated as follows:

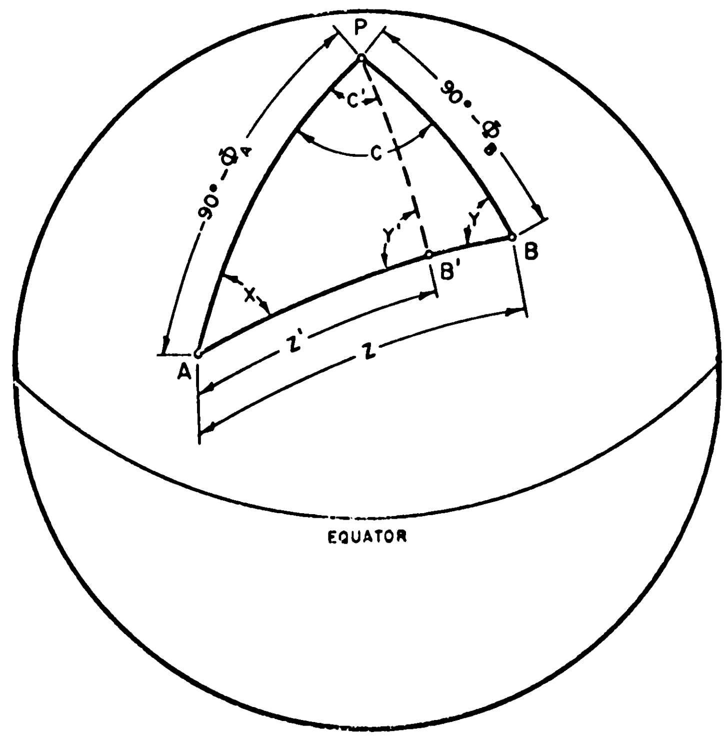


Figure 4.2-5 Spherical Triangle for Great Circle Path Computations

$$\tan \frac{Y - X}{2} = \cot \frac{C}{2}\left[\left(\sin \frac{\phi_B - \phi_A}{2}\right)\Big/\left(\cos \frac{\phi_B + \phi_A}{2}\right)\right] \qquad (4.2\text{-}7)$$

$$\tan \frac{Y + X}{2} = \cot \frac{C}{2}\left[\left(\cos \frac{\phi_B - \phi_A}{2}\right)\Big/\left(\sin \frac{\phi_B + \phi_A}{2}\right)\right] \qquad (4.2\text{-}8)$$

$$\frac{Y + X}{2} + \frac{Y - X}{2} = Y, \text{ and } \frac{Y + X}{2} - \frac{Y - X}{2} = X. \qquad (4.2\text{-}9)$$

The great circle distance, Z (in degrees), is given by

$$\tan \frac{Z}{2} = \tan \frac{\phi_B - \phi_A}{2}\left[\left(\sin \frac{Y + X}{2}\right)\Big/\left(\sin \frac{Y - X}{2}\right)\right].$$

4.2.16.3 To convert the angle Z obtained in degrees from (4.2-10) to kilometers of length, the following is used:

$$d_{km} = 111.12\ Z^\circ. \qquad (4.2\text{-}11)$$

4.2.16.4 The following formulas show how to calculate either the latitude or the longitude of a point on the great circle path, when the other coordinate is given. The given coordinates correspond to the edges of detailed maps, and to intermediate points usually about 7.5 minutes apart, so that straight lines between points will adequately approximate a great circle path.

4.2.16.5 For predominantly east-west paths, calculate the latitude $\phi_{B'}$ for a given longitude difference C':

$$\cos Y' = \sin X \sin C' \sin \phi_A - \cos X \cos C' \qquad (4.2\text{-}12)$$

$$\cos \phi_{B'} = \sin X \cos \phi_A / \sin Y'. \qquad (4.2\text{-}13)$$

4.2.16.6 For predominantly north-south paths, calculate the longitude difference C' for a given latitude $\phi_{B'}$:

$$\sin Y' = \sin X \cos \phi_A / \cos \phi_{B'} \qquad (4.2\text{-}14)$$

$$\cot \frac{C'}{2} = \tan \frac{Y' - X}{2} \left[\left(\cos \frac{\phi_{B'} + \phi_A}{2} \right) \Big/ \left(\sin \frac{\phi_{B'} - \phi_A}{2} \right) \right] \qquad (4.2\text{-}15)$$

Where the bearing of a path is close to 45 degrees, either method may be used.

4.2.17 Path Clearance

4.2.17.1 When the atmosphere is sufficiently sub-refractive (large positive values of the refractive index gradient), the ray paths will be bent in such a way that the bulge of the earth, or specific terrain features, appear to block the path between transmitter and receiver. In such cases, there is no longer a line-of-sight ray path, and energy transfer between the terminals is by diffraction over the terrain. The loss in signal under such conditions has been called diffraction fading. It may be alleviated by installing antennas which are so high that even the most severe ray bending will not interpose obstacles to the direct ray path.

4.2.17.2 Diffraction theory applicable to near line-of-sight analysis indicates that the direct path between the transmitter and the receiver needs a clearance above ground of at least 60 percent of the radius of the first Fresnel zone to approximate near free-space propagation conditions. Making allowance for possible sub-refraction is usually done by ensuring that the required clearance is maintained even when the effective earth radius is reduced below its normal value. Radio link designers in the United States and the United Kingdom often require that 60 percent of the first Fresnel zone radius shall be clear of intervening terrain even when the effective radius of the earth is reduced to 4500 kilometers (k = 0.7) [7] (pp. 115 and 116). When statistics of occurrence of sub-refractive conditions are known, it is possible to replace this "rule-of-thumb" by more accurate procedures which take into account the actual time distribution of sub-refractive gradients in specific areas.

4.2.17.3 Path clearance near the antennas should be considered in terms of three-dimensional beam clearance. A good model for the beam volume near a terminal is a cylinder having a cross-section of the same shape and dimensions as the antenna aperture. The antenna and beam volume should generally be kept at a minimum of three meters above the ground at the site. This precaution should be taken to prevent radiation hazards as well as to prevent beam blockage by people, vehicles, security fences, etc.

4.2.18 Fresnel Zones

4,2.18.1 The Huygens-Fresnel wave theory states that the electromagnetic field at a point, S_2, (figure 4.2-6) is due to the summation of the fields caused by reradiation from small incremental areas over a closed surface about a point source, S_1, provided S_1 is the only primary source of radiation. The field at a constant distance, r_1, from S_1 (a spherical surface) has the same phase over the entire surface since the electromagnetic wave travels at a constant speed in all directions in free space. This constant phase surface is called a wave front. If the distances, r_2, from various points on the wave front to S_2 are considered, the contributions to the field at S_2 will be seen to be made up of components that add vectorially in accordance with their relative phase differences. Where the various values of r_2 differ by $\lambda/2$ (half wavelength), the strongest cancellation occurs. Fresnel zones distinguish between the areas on a closed surface about S_1 which add and those which cancel.

4.2.18.2 Consider a moving point, P, in the region about the terminal antenna locations S_1 and S_2 such that the sum of the distances r_1 and r_2

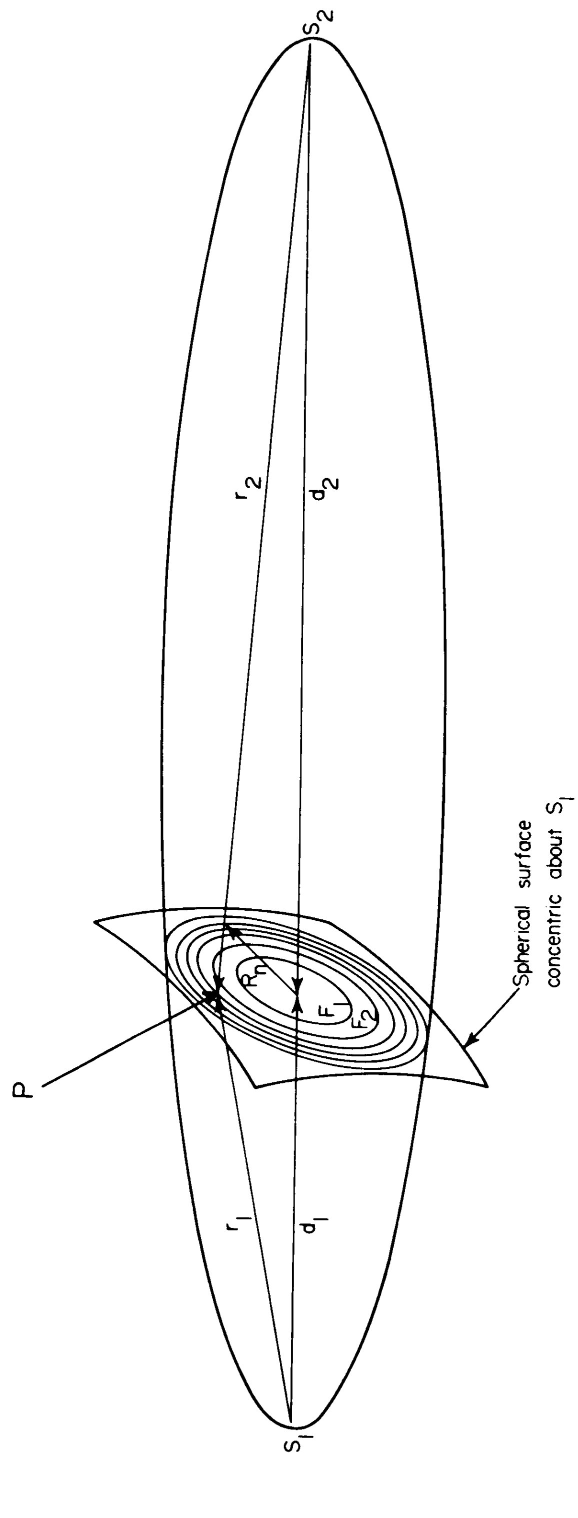


Figure 4.2-6 Fresnel Zone Geometry

from the antennas to P is constant. Such a point will generate an ellipsoid with S_1 and S_2 as its foci. Now define a set of concentric ellipsoidal shells so that the sum of the distances r_1 and r_2 differs by multiples of the half wavelength $\lambda/2$. The intersection of these ellisoids with any surface defines Fresnel zones on the surface. Thus, on the surface of the wave front, a "first" Fresnel zone F_1 may be defined as bounded by the intersection with the sum of the straight line segments r_1 and r_2 equal to the distance d plus one-half wavelength $\lambda/2$. The second Fresnel zone, F_2, is defined by the region where $r_1 + r_2$ is greater than $d + \lambda/2$ and less than $d + 2(\lambda/2)$. Thus, F_n is the region where $r_1 + r_2$ is greater than $d + (n - 1)\lambda/2$ but less than $d + n\lambda/2$. Field components from even Fresnel zones tend to cancel those from odd zones since the second, third, and fourth zones, etc., are approximately equal in area.

4.2.18.3 The concept of Fresnel zones is not meaningful for the "near field" within short distances of practical antennas. A rule of thumb for determining the minimum distance, d_F, at which the zones become meaningful is that d_F be greater than $2D^2/\lambda$, where D is the maximum dimension of the antenna aperture in the same units of length as λ.

4.2.18.4 A good approximate equation (valid for almost all microwave applications) for the outside boundary of the nth Fresnel zone radius, R_n, on a surface perpendicular to the propagation path is

$$R_n \cong \sqrt{n\lambda\left(\frac{d_1 d_2}{d_1 + d_2}\right)} \qquad (4.2\text{-}16)$$

or

$$R_n \cong 17.3\sqrt{\frac{n}{f_{GHz}}\left(\frac{d_1 d_2}{d_1 + d_2}\right)}. \qquad (4.2\text{-}17)$$

In the first equation all distances and the wavelength λ must be in the same units. λ must be small compared to the distance and antenna heights involved, and r_1+r_2 (from paragraph 4.2.18.2) should not be significantly larger than d_1+d_2. In the second equation all distances are in kilometers, the frequency is in GHz and the Fresnel zone radius is in meters. If R_1 is the radius of the first Fresnel zone, then

$$R_n \cong R_1\sqrt{n}\ . \qquad (4.2\text{-}18)$$

Because the higher numbered zones tend to be self canceling, they are not significant for many calculations; however, consideration of the higher order zones is helpful in understanding obstacle diffraction, or the use of diffraction gratings as passive repeaters (see sect. 4.4. 39).

4.2.19 Terrain Reflections

4. 2.19.1 Potential reflection surfaces can often be identified by examination of terrain profiles; also the blockage of reflected signals by terrain obstacles may be evaluated in this manner. However, the magnitude and other characteristics of terrain reflections may either be specular (from a smooth surface) or scattered (from a rough surface). A smooth surface is one for which the phase difference between reflected component rays is small, resulting in an almost unperturbed plane-wave being reflected. A rough surface imparts considerable phase shift to the individual rays, resulting in partial interference between them which will produce an irregular scattering pattern.

4.2.19.2 The Rayleigh criterion is often used to determine whether a surface will produce a mainly scattered or a specular reflection. The reflection is considered specular if

$$\sigma < \frac{\lambda}{32 \sin \alpha}, \qquad (4.2\text{-}19)$$

where σ is the standard deviation of the differences in height of the surface, λ is the wavelength and a is the angle of incidence. σ and λ must be in the same units.

4. 2.19.3 Terrain roughness parameters applicable to practical microwave links may vary greatly with time and season; i. e. , ground

reflection coefficients and roughness will vary with snow cover, air humidity and temperature immediately above the ground, and with the period in the life cycle of ground cover vegetation. Effective "roughness" of water surfaces will vary with wave height.

4.2.19.4 A word of caution when considering Fresnel zones in connection with surface reflections: the Fresnel ellipsoids to be considered are those concentric about the line between one antenna and the image relative to the reflecting surface of the other antenna.

4.2.19.5 Reflections from terrain should be avoided if at all possible. Useful techniques are selection of paths with maximum terrain clearance and use of narrow beam antennas, although extremely narrow beams may cause fading by atmospheric defocusing. If terrain reflections cannot be avoided, the adverse effects can be greatly reduced through the use of vertical space or frequency diversity. More detailed analysis and information regarding reflections from terrain may be found in [41].

4.2.20 Initial Path Loss Estimates

4.2.20.1 Following ATT practices, "path loss" as used here is defined as the ratio of the power supplied to the terminals of the transmitting antenna to that available at the terminals of the receiving antenna. Path loss estimates must include consideration of the antenna beam characteristics, not only in terms of the power gains, but also in terms of the relations between the beam dimensions and the path geometry. The antenna beam width (the width at the half-power points) defines the cross section of the radio path and therefore the amount of terrain or atmosphere relevant to calculating or estimating path loss.

4.2.20.2 Many types of propagation effects produce attenuation or distortion of a radio signal; they include the physical phenomena of divergence, absorption, diffraction, reflection, and refraction. The attenuation or weakening' of microwave signals over line-of-sight paths can be classified in terms of constant and time-varying losses (fading). Understanding of these losses will contribute toward making reasonably accurate path loss estimates.

4.2.20.3 Some components of path loss are relatively constant. Examples are those due to the divergence of radiation from an antenna (which varies directly with the square of the distance), certain types of atmospheric absorption, some types of terrain reflections, and beam blockage near the antennas.

4.2.20.4 Time-varying losses include power fading and multipath fading (phase interference due to differences in component path delays). Within the classification of power fading are rain attenuation, water vapor absorption, beam deflection away from the desired antenna because of atmospheric reflection or refraction, and the terrain blockage associated with beam deflection caused by atmospheric refractivity changes. Multipath fading consists of phase interference between signals arriving over more than one path which are diffracted, reflected or refracted by changing atmospheric effects over each path. An important type of multipath fading is the fading from rain because of appreciable doppler shift in the reflected signals which causes distortion as well as attenuation of a broadband signal. The extent to which a modulated signal can be degraded because of scattering from rain is unknown at this time.

4.2.21 Free Space Basic Transmission Loss and Free Space Path Loss

4.2.21.1 The loss due to the divergence of radiation from a point in free space may be calculated by using the mathematical model of isotropic antennas (antennas which radiate energy equally in all directions) separated by the path length and isolated in free space. The loss between terminals of such hypothetical antennas is called the free space basic transmission loss, L_{bf}, and is expressed in decibels.

$$L_{bf} = 92.45 + 20 \log f_{GHz} + 20 \log d_{km} \text{ dB} \qquad (4.2\text{-}20)$$

This is the same expression (4. 2-1) already given in section 4.2.9, except that here the frequency f is in gigahertz. As before, d is the path distance in kilometers. The solution to this equation is presented graphically in figure 4. 2-7 for various frequencies and distance ranges.

4.2.21.2 The free space path loss L_{of} is defined here as the loss between the two antenna terminals in free space provided that the antennas are loss-free and properly impedance-matched to the transmitter and receiver, respectively. These conditions are normally met in the case of well-designed microwave line-of-sight links. The free-space path loss L_{of} is obtained by subtracting the maximum power gains, G_t and G_r in dB, of the transmitting and receiving antennas from L_{bf}, the free space path loss.

$$L_{of} = L_{bf} - G_t - G_r \text{ dB} \qquad (4.2\text{-}21)$$

The power gain of an antenna in a specified direction is 4π times the ratio of the power radiated per unit solid angle in that direction to the net power accepted by the antenna from its generator. A more complete discussion of antenna gain is given in [18] (p. 19), and will be presented in section 4.4.29.

4.2.22 Atmospheric Absorption

4.2.22.1 The path loss component caused by atmospheric absorption primarily due to oxygen and water vapor, varies with air density, temperature and humidity. Since oxygen absorption loss is dependent only upon air density and path length, this loss is fairly stable as a function of time. Water vapor absorption is more variable with time.

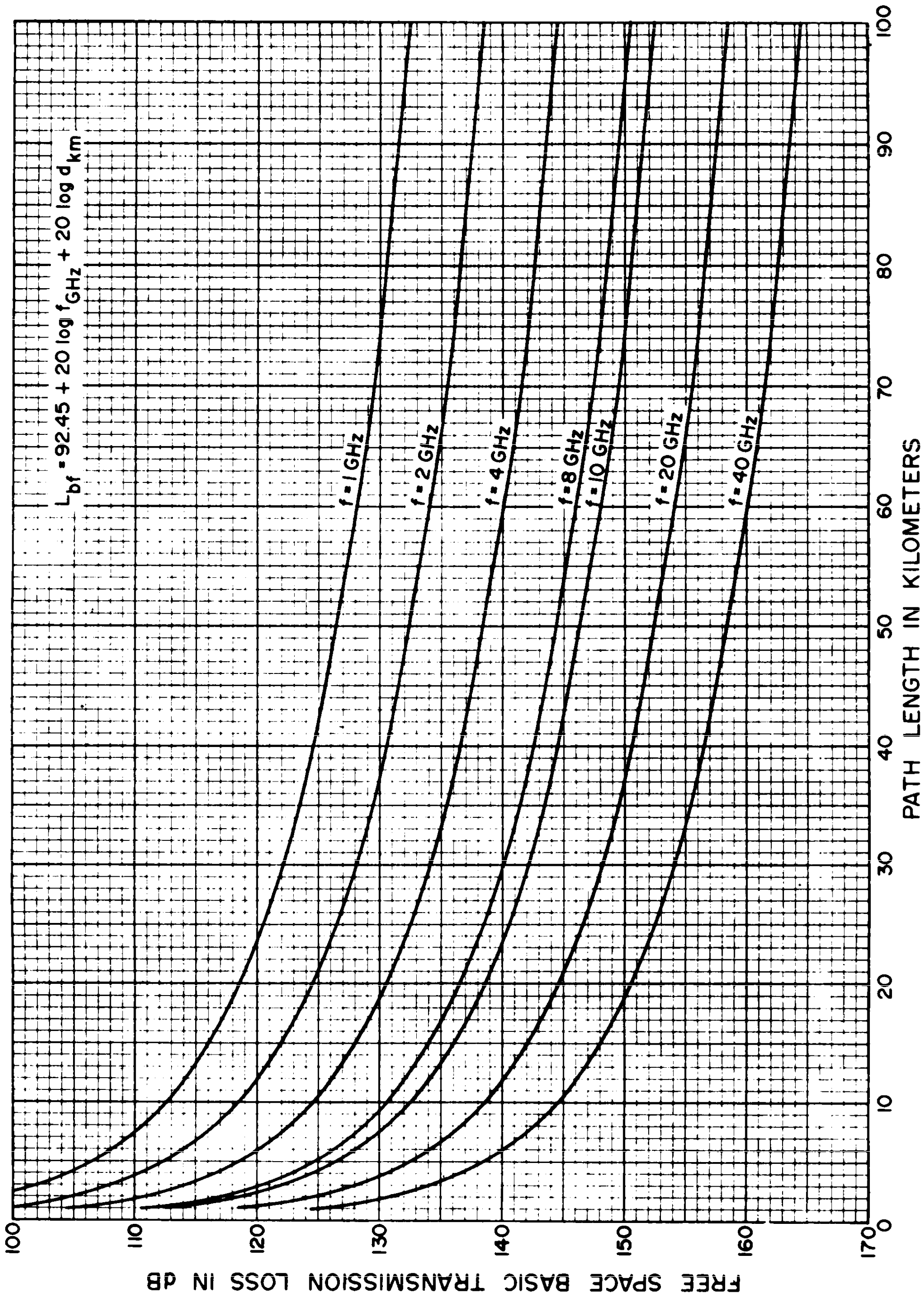


Figure 4.2-7 Free space basic transmission loss versus path length

The values of absorption for oxygen, y_{oo}, and water vapor, y_{wo}, are shown in figure 4.2-8 in decibels per kilometer as a function of frequency.

4.2.22.2 For frequencies between 1 and 10 GHz, as estimate of 0.01 dB per kilometer path length is a reasonable allowance for the total atmospheric absorption. Between 10 and 40 GHz the values of figure 4.2-8 are added together and then multiplied by the path length to estimate the value of the average atmospheric absorption. For paths located at high terrain elevations, or for paths with elevation angles greater than 0.5 degrees, such an estimate will be slightly too large. For a first estimate, the values from figure 4. 2-8 will generally be sufficient even though the losses will vary with humidity and air density.

4.2.22.3 The upper limit of attenuation due to fluctuations in the water vapor content of the air is approximately one and one-half times that shown by the curve for y_{wo}. because the upper limit is based on higher temperatures and greater relative humidity. It should be remembered that conditions for maximum water vapor absorption will often coincide with those producing additional attenuation because of rain.

4.2.23 Attenuation Due to Precipitation

4.2.23.1 The attenuation of radio waves by suspended water droplets and rain often exceeds the effects of combined oxygen and water vapor absorption. Water droplets in fog or rain will scatter radio waves in all directions whether the drops are small compared to the wavelength or comparable to the wavelength. In the latter case, raindrops trap and absorb some of the radio wave energy; accordingly, rain attenuation is much more serious at millimeter wavelengths (frequencies above about 10 GHz) than at lower frequencies.

PRESSURE 760mm Hg
TEMPERATURE 20°C
WATER VAPOR DENSITY 10g/m^3

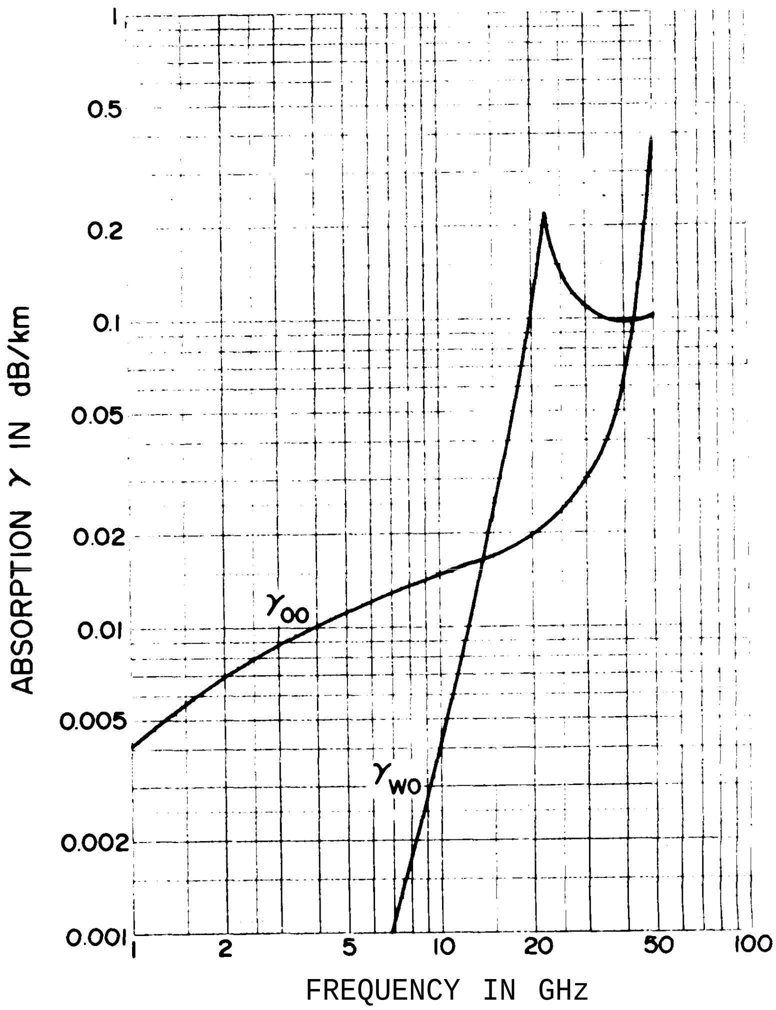


Figure 4.2-8 Surface values 7_{00} and $\sim_{wo}$ of absorption by oxygen and water vapor

4.2.23.2 The attenuation effects of rain, while small in the lower microwave region, become more important at frequencies above 10 GHz. In Japan, for example, at 15.4 GHz, a uniform rain falling at the rate of 100 mm/hr has been observed to produce an excess attenuation of about 7 dB/km [87]. In the United States, over a 4.7 km path at 14.4 GHz, as much as 48 dB attenuation was observed at a time when the average rainfall rate was 137 mm/hr [19]. Also in the United States, a uniform rain, falling at the rate of 100 mm/hr was observed to produce an excess attenuation of about 9 dB/km at 18 GHz [16]. Under these conditions, it is obviously impossible to maintain transmission over paths longer than a few kilometers. However, recent investigations have shown that the temporal and spatial distributions of such severe rain storms are highly restricted [16], and therefore parallel paths a few km apart may provide an effective diversity improvement (see paragraph 4.2.6.2). The excess attenuation caused by rainfall is the controlling factor above 15 GHz; therefore, radio relay systems operating at these frequencies will have to employ short hops if they are to have a high degree of reliability (see figure 4.2-1).

4.2.23.3 Conventional diversity configurations, either vertical space or frequency diversity, cannot be used to minimize the effects of rain attenuation. Route diversity configuration may be used. Such methods of obtaining reliability above 10 GHz are expensive but are worthy of consideration.

4.2.24 Estimating Rain Attenuation

4.2.24.1 To estimate time distributions of rain attenuation fading for a path in a given area, it is necessary to know three things: one, the attenuation per kilometer as a function of rainfall rate (figure 4.2-9); two, the time distribution of rainfall rates for the geographic area (figure 4.2-10 together with 4.2-11); and three, the spatial distribution of rain rates. The information for figure 4.2-9 showing attenuation per kilometer was obtained from [7] p. 179. The time distributions of rainfall rates and the zone map of the continental United States (figures 4.2-10 and 4.2-11) were computed from statistics on maximum five minute rainfall rates expected once in two years [19].

4.2.24.2 In order to make the use of the information from these figures more convenient, time distributions in terms of attenuation per kilometer (see figures 4.2-12a to c) have been prepared for each zone (figure 4.2-11) from the rain rate- time distributions (figure 4.2-10) and the graph of rain attenuation as a function of rain rates (figure 4.2-9). A rough estimate of the time distribution of rain attenuation for a given path may be obtained by multiplying the length of the path, or 10 kilometers, whichever is less, by the ordinate values of attenuation per unit of length. The 10 kilometer limit is based on estimates of average storm cell diameters. These distributions will provide one of the components in the estimation of fading depth when making initial path loss calculations.

4.2.24.3 Figure 4.2-13 is a map of the world showing rain zones defined in a similar manner as those used for the United States (figure 4.2-11). It is not intended to provide the detail required for design of systems in a particular locality; rather, it should be used as a rough indicator of the general areas in which rain attenuation may be a significant design consideration. For most parts of the world, precipitation rate data are either very limited or not available; this rain zone map is based primarily on maximum one-hour rain data of reference [21] but also includes information based on work presented in [22 - 27]. Terrain effects are important considerations in the interpretation of this map, particularly in the case of relatively small but mountainous islands. Note, for example, that Hawaii is identified

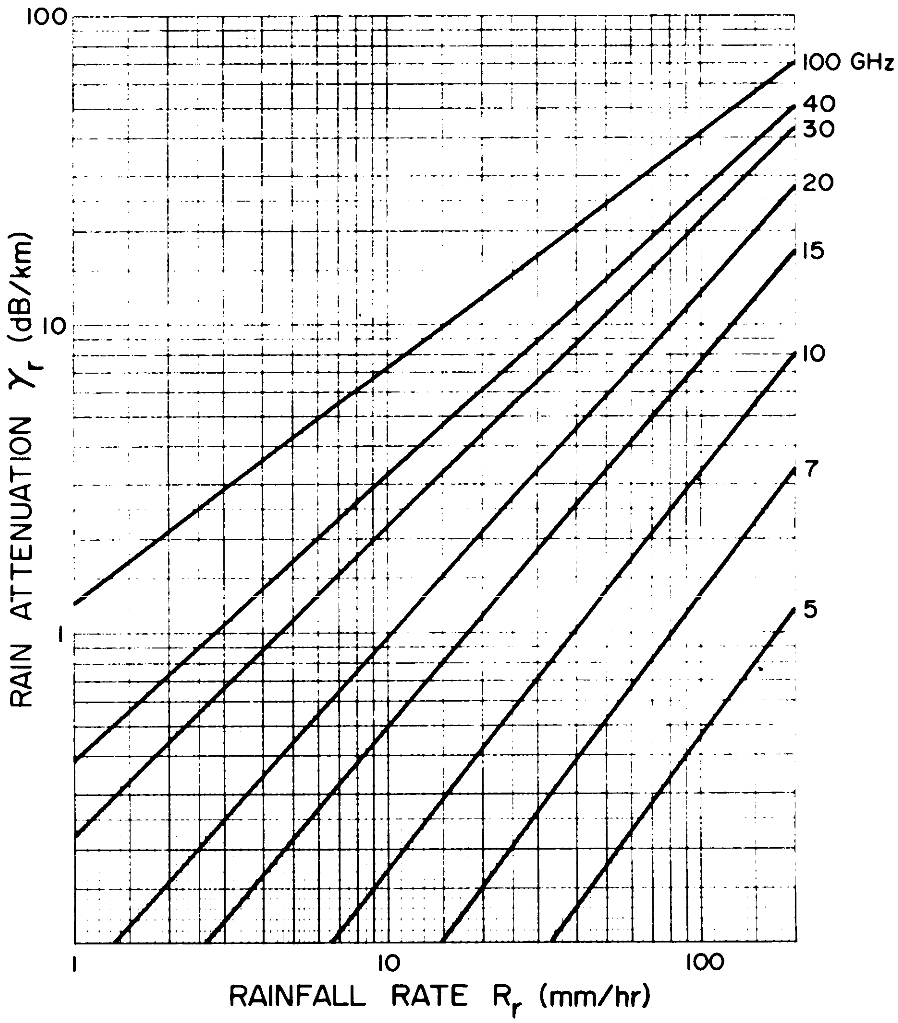


Figure 4.2-9 Rain attenuation versus rainfall rate between 5 and 100 ghz

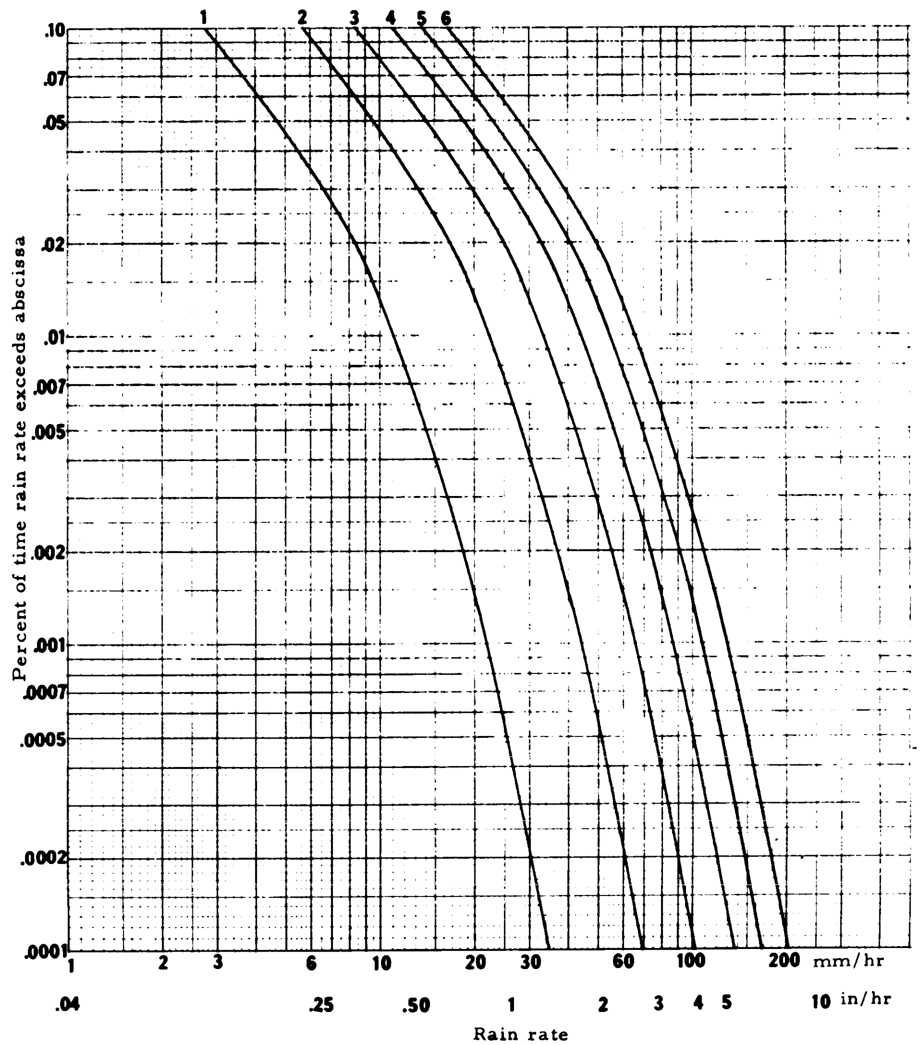


Figure 4.2-10 Rainfall rate-time distributions for six climatic zones

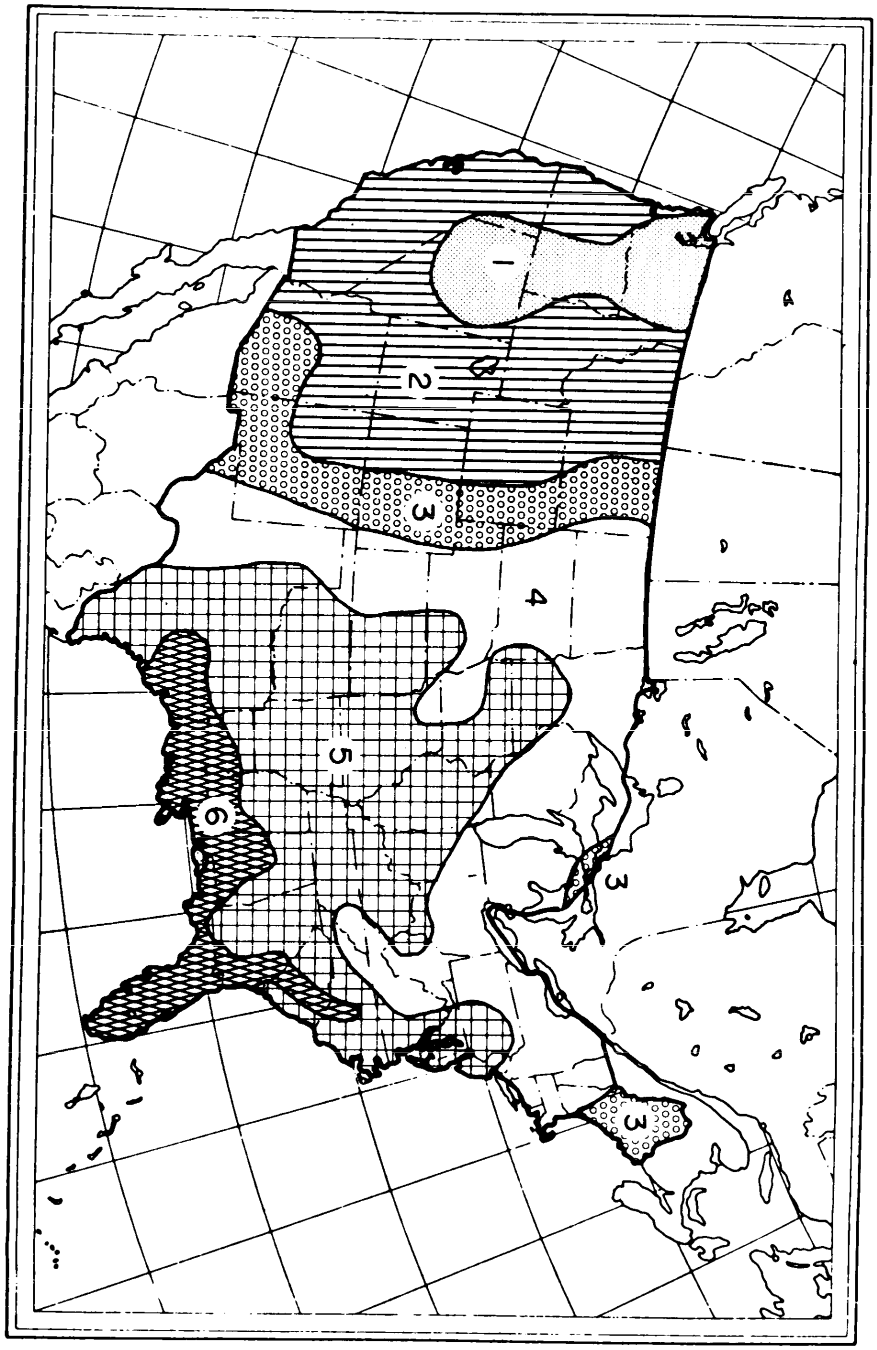


Figure 4.2-11 Zones of maximum five-minute rainfall rates

Figure 4.2-11

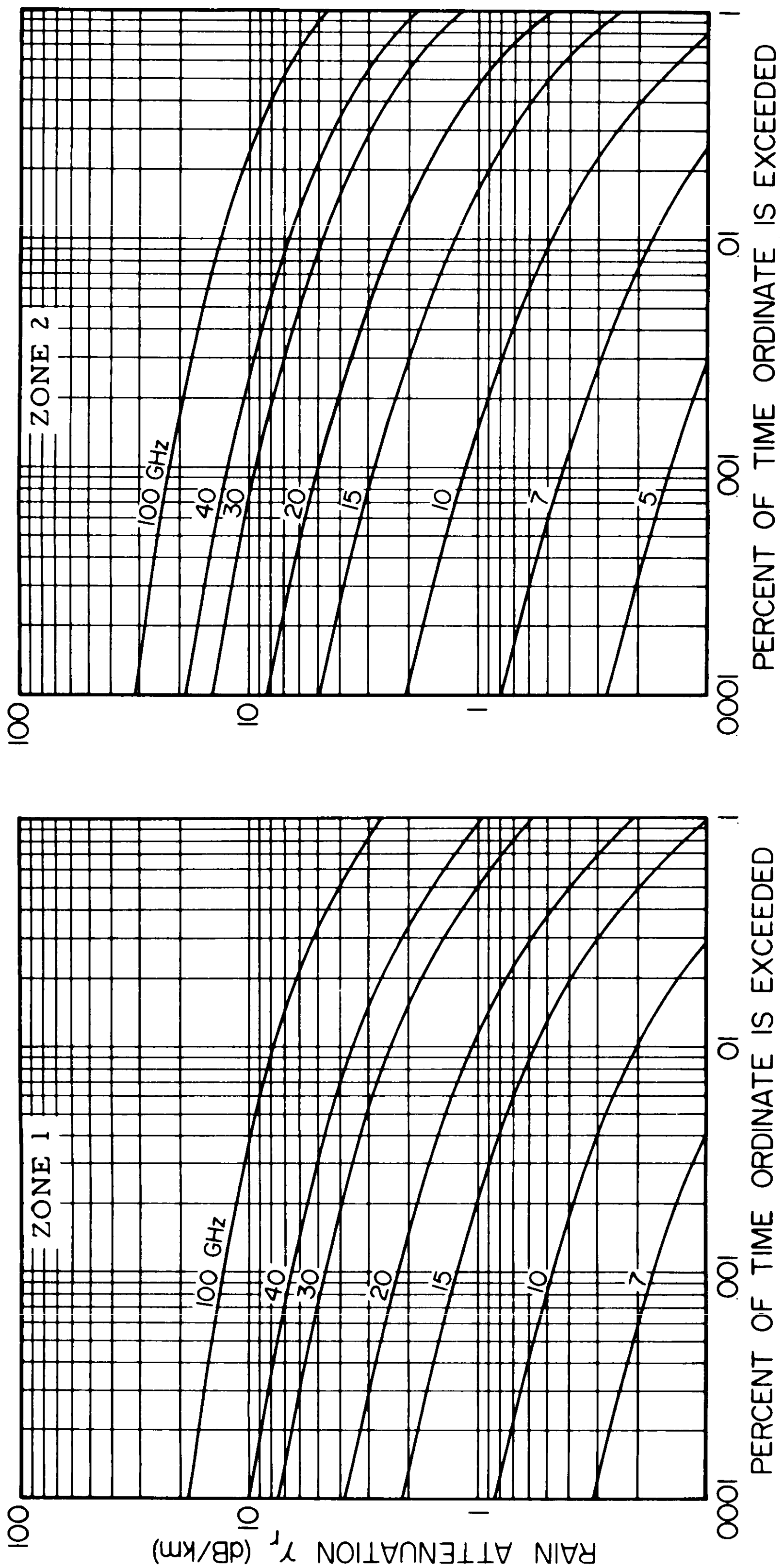


Figure 4.2-12a Time Distributions of Rain Attenuation per Kilometer of Path Length for Rain Rate Zones 1 and 2

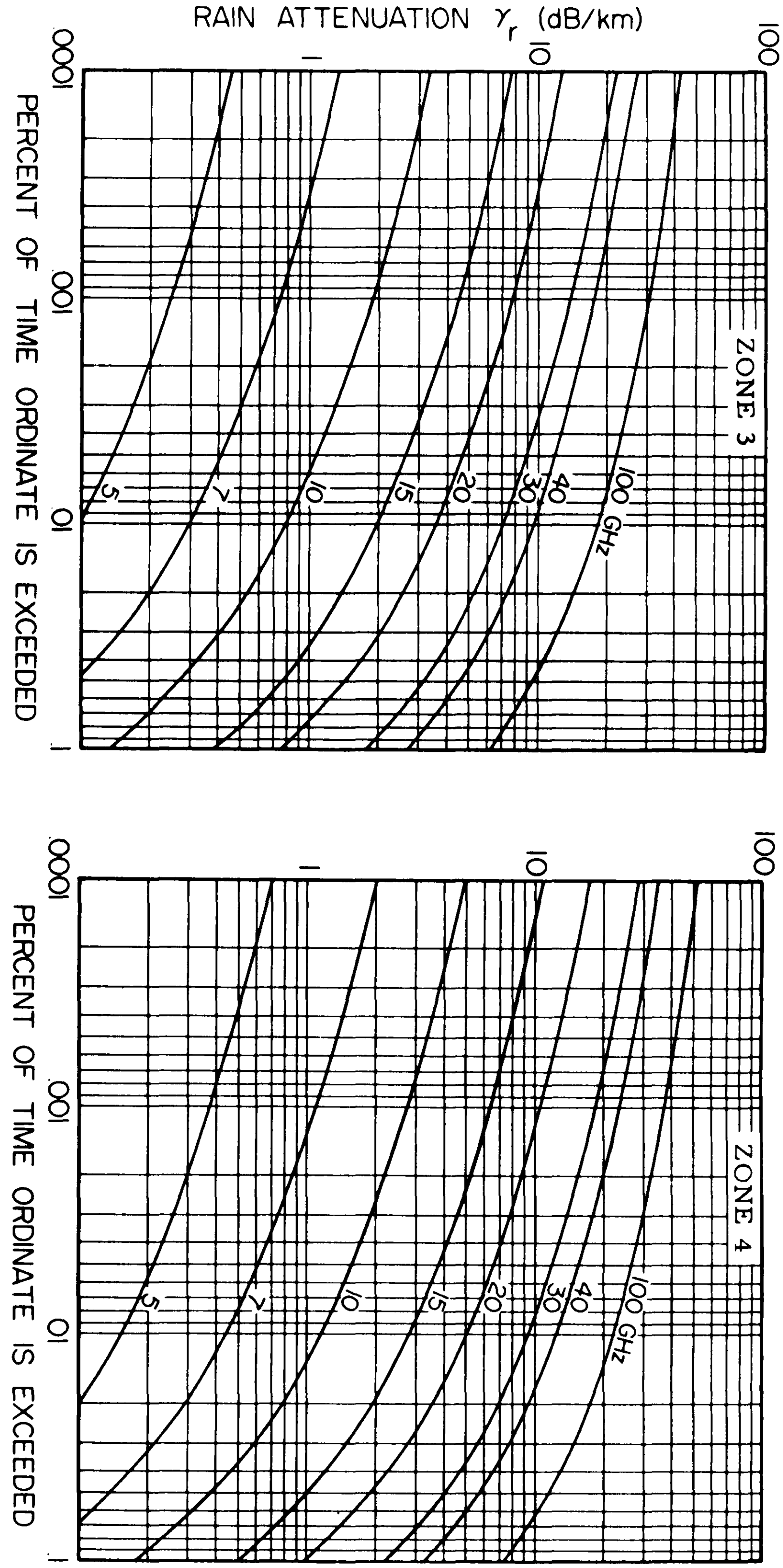


Figure 4.2-12b Time Distributions of Rain Attenuation per Kilometer of Path Length for Rain Rate Zones 3 and 4

Figure 4.2-12b

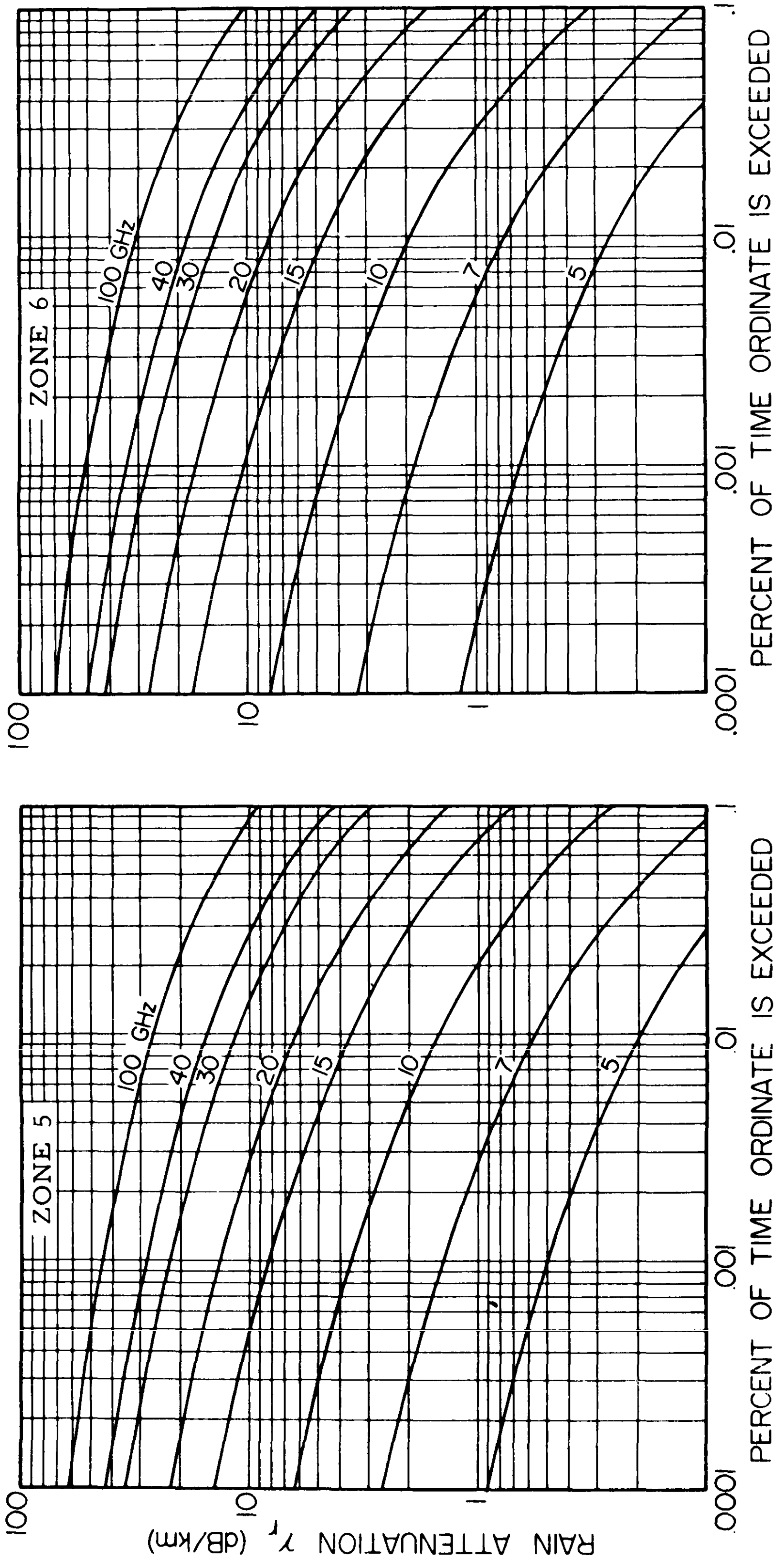


Figure 4.2-12c Time Distributions of Rain Attenuation per Kilometer of Path Length for Rain Rate Zones 5 and 6

Figure 4.2-12c

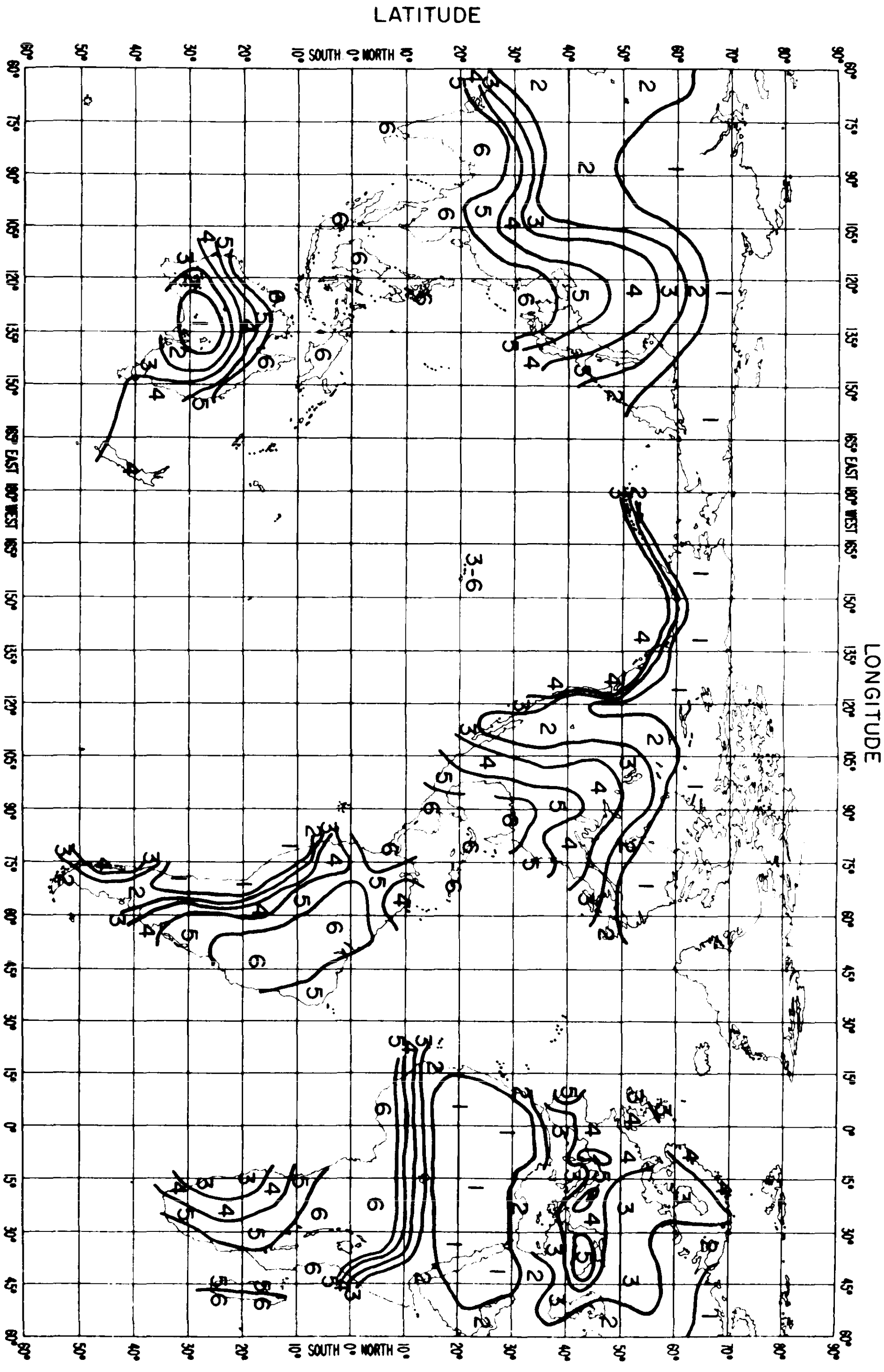


Figure 4.2-13 World Rain Rate Zones

Figure 4.2-13

by zones 3 - 6. Slopes exposed to the prevailing (trade) winds may have very heavy average rainfall while areas on the lee side of the islands may be quite dry. Similar climatic modifications also occur on the larger land masses, i. e. , when moist winds are lifted by a mountain chain, the windward slopes tend to have heavier precipitation than the lee side. Also, in mountainous regions precipitation tends to increase with altitude [31]. An increase in precipitation probability in Colorado averaging nearly five percent per 1000 feet elevation gain (during July and August) was reported in [32].

4.2.24.4 Rainfall attenuation estimates for regions outside the United States should, whenever possible, be based upon rainfall rate or attenuation data available from ETAC (USAF Environmental Technical Application Center) or foreign meteorological services and radio propagation laboratories. The rainfall zone information shown in figure 4.2-13 in conjunction with the attenuation curves for the United States (figure 4. 2-11) will provide only rough estimates.

4.2.25 Atmospheric Refraction

4.2.25.1 Changes in atmospheric refraction sometimes cause severe fading on line-of-sight microwave radio links. For detailed information on this topic, see section 4.4.6. The gross behavior of the variation in transmission loss for many paths is explained by means of two relatively basic propagation mechanisms: refraction associated with the time-varying vertical gradient of refractive index and the formation of phase-interference patterns because of diffraction and reflection by the earth's surface and atmospheric refractive index discontinuities. Refraction can also cause fading when extreme conditions cause the ray to arrive at an angle off the main-beam axis of the receiving antenna (par. 4.2.25.3).

4.2.25.2 Measurements of the vertical refractive-index gradient in the lower layers of the atmosphere show that the range of values is extremely large. The following statement is taken from [7], page 115: "In the United States, at Cape Kennedy, Florida, the vertical gradient was measured in the first 100 meters near the surface of the earth. It was found to vary between +230 N units/km, which was exceeded 0.05 percent of the time, and -370 N units/km, which was exceeded during 99.9 percent of the time, which corresponds to k values of 0.4 and -0.7 respectively." These variations are typical for most parts of the world but the very extreme values need not always be allowed for in system design because of their limited extent in time and space. For most parts of the world gradient variations between +70 and -140 N units/km (corresponding to 0. 7 $\leq k \leq$ 10) are more typical.

4.2.25.3 Variation of atmospheric refraction can cause changes in the apparent angle-of-arrival of the line-of-sight ray particularly in the vertical plane, and can therefore cause effectively a reduction in gain in the antennas used at the radio path terminals. Measurements made in the United States over a path of 28 kilometers, at frequencies of 4 and 24 GHz, show that the angle-of-arrival can change rapidly by as much as 0.75 degrees above and below the normal line of sight [7], page 117. The angle-of-arrival variation in the horizontal plane is usually much less, being of the order of 0.1 degrees. Measurements in other parts of the world show less variation, but generally the variations become larger as the climate becomes hotter and more humid. Because of the vertical variations in angle-of-arrival, antennas having half-power beamwidths less than 0.5 degrees should generally be avoided for line-of-sight paths. This limitation can be used as one criterion to determine maximum aperture size for antennas and the maximum vertical dimension for passive repeaters (fig. 4.4-33). Note that the dimensions for antennas are given in feet because of the nominal values generally available from U.S. manufacturers.

4.2.26 Multipath Fading

4.2.26.1 Multipath effects occur in two forms: reflection from the ground or water surfaces, and refraction or reflection by inhomogeneities in the atmosphere.

4.2.26.2 Under some circumstances, the direct ray will be interfered with by the ground-reflected ray or other multipath rays. The most severe fading occurs when there are two effective components of the same order of magnitude varying in their relative phase. Measurements made in the United States show that as many as six significant components may exist at one time [84].

4.2.26.3 Multipath propagation measurements carried out in Japan [85] show that most of the deep fades are caused by destructive interference between two dominant rays and that the path-length difference between these rays varies to a considerable extent from path to path. Maximum path length differences on the order of many wavelengths can be observed on oversea as well as on overland paths.

4.2.26.4 Very severe fading can occur on over-water paths when the point of specular reflection falls on the water. If such a path cannot be avoided, height or frequency diversity may be used to reduce the severity of the fading. Alternatively, fading can be reduced considerably if the geometrical point of reflection on the water is screened from one or the other of the terminals by the terrain (even if some of the surface of the water is still visible from both terminals). However, experience on one over-water path 80 kilometers long showed that it was very difficult to achieve transmission of complex signals, such as color television, if the water surface was not completely invisible from at least one terminal [86].

4.2.26.5 Under normal conditions and over moderately rough sea or irregular terrain, one expects a portion of the ground-reflected wave to be scattered out of the propagation path. However, when the atmosphere is super-refractive and the surface appears concave, the reflected wave is enchanced by the convergence of the associated rays.

4.2.26.6 In addition, experiments in Germany have revealed that total reflection can occur in an atmospheric layer near the ground, this layer being connected mostly with mist or ground fog experienced over moist river valleys or moors [88]. Some earlier work carried out in The United Kingdom also shows correlation between fading and ground fog [89].

4.2.26.7 The frequency of occurrence and observation of multipath fading caused by layering in the atmosphere is related to the variation of the structure of refractive index with time; i. e. , the worst propagation conditions are likely to occur during periods of extreme stratification of the atmosphere. On overland paths and in temperate climates, such conditions normally exist during the night and early morning hours of summer days. Reflections from rapid changes of the refractive index within a height range of several tens of meters above the surface of the earth can be a source of multipath propagation.

4.2.26.8 For designing radio relay systems conforming to DCA Standards it is often necessary to predict the probability of outages due to deep fades for very small percentages of the time (i. e. , on the order of 0.01 percent for an average hop of about 50 kilometers). If dual vertical space diversity or dual frequency diversity is used and fades on the two sets of equipment are not well correlated, prediction of the probability of the fade depth must be made for approximately

0.01 percent of the time. Although diversity aids in preventing outages caused by interference fading, outage time cannot be directly equated to depth and frequency of fading of the combined signal because multi-path causes distortion as well as attenuation. The fading depth exceeded for a small percent of the time increases with path length and increases slightly with frequency. Multipath fading is also a function of the terrain near the path, the atmospheric conditions, and the angle of penetration through the atmosphere.

4.2.26.9 Fades due to non-linear refractive index gradients (stratified atmospheric layers) are usually also of the multi path, phase interference type, and can occur even when there are no reflections from terrain. A combination of ray paths caused by both ground and atmospheric layer reflections can produce very severe fading. Non-linear refractive index gradients are most likely to occur during the night, with light winds, clear skies, and high humidity near the surface.

4.2.27 Estimating Multipath Fading

4.2.27.1 An empirical formula based on the work by Barnett [83] and quoted in [4; see p. 119] can be used to estimate the percentage of time within a year, P_{mf}, that fades exceed a specified depth below free space for a given path and frequency. This formula applies to paths within the United States, and does not specifically consider beam penetration angle through the atmosphere or the beam clearance of terrain:

$$P_{mf} = a \times b \times 6.0 \times 10^{-5} \times f \times d^3 \times 10^{-mf}/10\% \qquad (4.2\text{-}22)$$

where

a =
- 4 : for very smooth terrain, including overwater
- 1 : for average terrain, with some roughness
- 1/4 : for mountainous, very rough or very dry terrain

b =
- 1/2 : gulf coast or similar hot, humid areas
- 1/4 : normal interim temperate or northern climate
- 1/8 : moutainous or very dry climate

f= frequency in GHz
d= path length in km
M_f= fading depth exceeded below free= space level, in dB.

Note that for performance calculations as outline in section 4.5 the longterm median level $P_r(0.5)$ should be used as a reference level instead of the free-space level.

4.2.27.2 The above formula has been checked by measurements In the 4, 6, and ll GHz bands [83]. A similar type formula is provided in [7], p. 119, based on measurements made in Japan.

4.2.28 Combining Path Loss Contributions and Grading Paths

4.2.28.1 For the initial comparative evaluation and ''grading" of potential links, only minimum tower heights should be used, which are sufficient for clearing local obstacles such as tree or buildings. In this manner, all potential paths can be compared on a common basis. Paths with insufficient clearance should be rejected outright unless no better paths are available.

4.2.28.2 For each path, those path loss contributions in decibels should be added up which are relatively constant with time. These are the free-space loss L_{of}(see section 4.2.21) and the average oxygen absorption from section 4.2.22. Allowances for multipath and other fading conditions may also vary between potential links of a system, and these will be discussed in the following sections. In general, conditions favorable for the formation of heavy rain showers tend to mix the lower atmosphere and eliminate multipath fading, particularly on short links which will normally be used at frequencies above 15 GHz. However, on very long LOS links, the simultaneous occurrence of fading due to multipath and rain is more likely. Resulting total path loss values are then compared and those paths with the lowest values are selected unless other considerations apply. For paths over 10 km long, the largest estimate for water vapor absorption should be added to the distribution for rain attenuation loss because these losses are likely to occur at the same time.

4.2.29 Fading Estimates for Long LOS Links

4.2.29.1 It may be necessary at times to design long line-of-sight links because of inaccessible or otherwise unusable terrain (for relays), or systems extending over large bodies of water. In order to achieve line-of-sight conditions over paths as long as 200 km, terminals must be located on mountain tops. For such paths, atmospheric and terrain characteristics at and near mid-path is usually very critical since the clearance between the ray path and the terrain is at a minimum, and also because the angle of penetration between the ray path and the atmospheric layers is small. Particularly if the midpath region is over water or broad river valleys, small penetration angles in conjunction with atmospheric stratification can produce severe fading which is sometimes quite prolonged (hours or days) because of defocusing of the energy, or trapping of energy in surface or elevated ducts so that the desired terminal cannot be reached.

4.2.29.2 Although the literature contains may qualitative statements regarding fading on long LOS links, few specific recommendations for design exist. In general, recommendations call for greatest possible terrain clearance at any point of the path, particularly for over-water links, since strongest s gratification exists usually near the surface. A minimum clearance of 50 m between the ray path and the terrain is recommended [4] p. 52. However, this is an arbitrary figure, and would not necessarily apply to any type of terrain and to all atmospheric conditions.

4.2.29.3 For frequencies between 2 and 7 GHz, some quantitative information has been derived in [3] (p. 63) for long paths. Three categories of fading are described (A, B, and C), and curves of expected fading depths versus path distance are shown in figure 4.2-14 for 0.1 percent and 1 percent of the time during the month with most severe fading.

Curve A - type-A fading relates to hops with "favorable" fading characteristics:

- rare occurrence of atmospheric stratification;
- rare occurrence of calm weather;
- above hilly country, but not above wide river valleys and inland lakes;
- in high mountainous country, with radio paths high above the valleys;
- for hops between points in a plain or a valley and mountain tops where the angle of elevation relative to the horizontal plane exceeds approximately 0.5° for the lower station;

Curve B - type-B fading relates to hops with "normal" fading characteristic:

- above flat country if stratification is formed only occasionally;
- above hilly country, but not above wide river valleys and inland lakes;
- in coastal areas with moderate temperatures but not over the sea;
- for hops with a steep angle of elevation also in hot and tropical regions;

Curve C - type-C fading relates to hops with "unfavorable" fading characteristics:

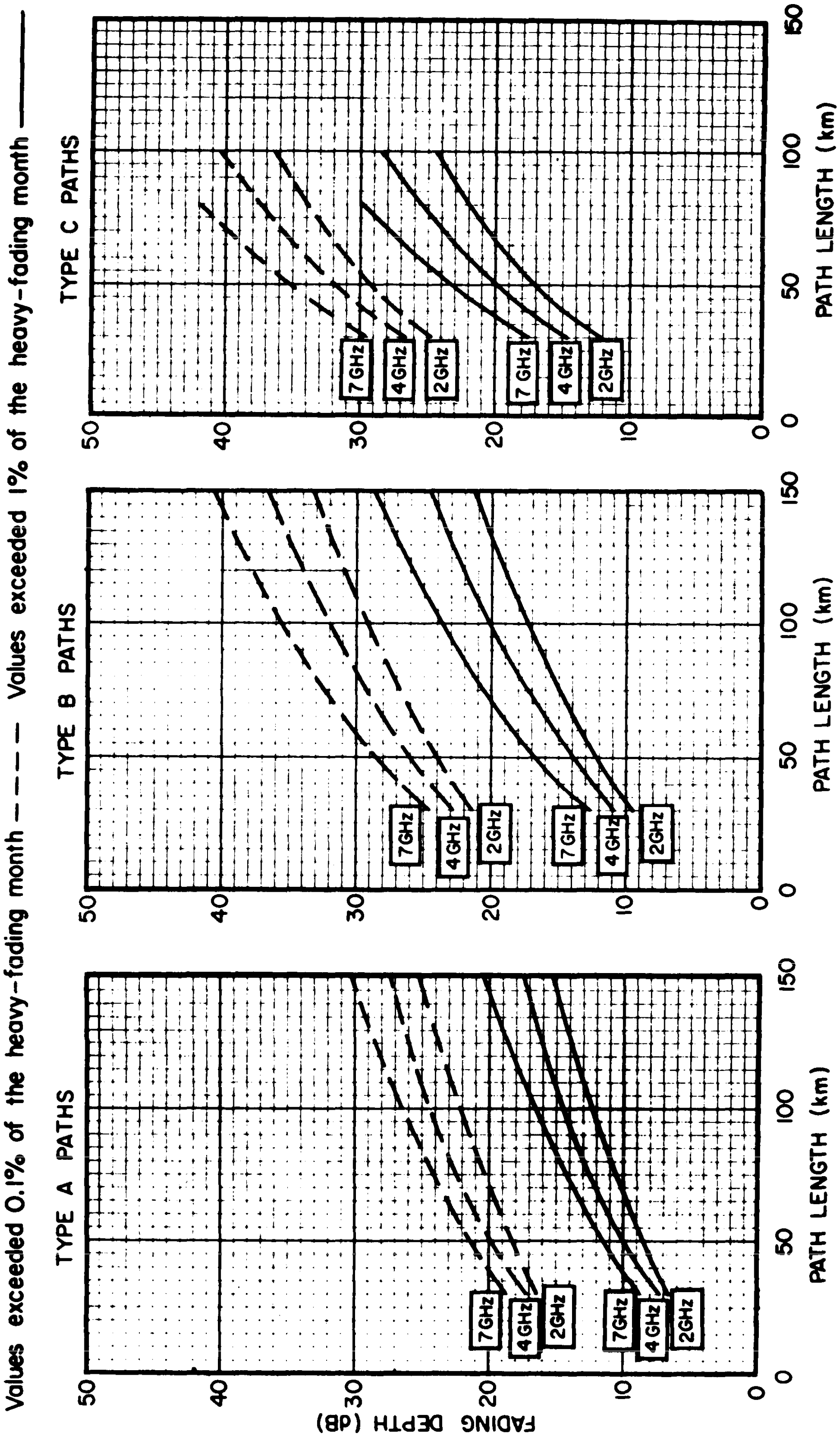


Figure 4.2-14 Fading Allowances for Long Line-of-Sight Paths

Figure 4.2-14

above humid areas where ground mist is apt to form and especially to hops with a flat path above flat ground; for example, wide river valleys, moors;

near the coast in hot regions and, generally, in tropical regions, to hops not operating with a large angle of elevation over-water links.

4.2.29.4 The information in figure 4.2-14 is provided to estimate fading depths that are exceeded for small percentages of time for paths up to 150 km, and is based on information in [3]. Since much of this fading is due to multipath, the outage time represented by the fading depths in figure 4.2-14 can be reduced using either frequency or space diversity.

4.2.30 Additional Route Considerations

4.2.30.1 After grading potential links and making comparisons on the basis of profiles and path loss distributions, certain sets of these links will form routes which will appear good choices for further evaluation. Additional factors that must be considered and weighed carefully for their contribution in system performance are (1) localized meteorological conditions and detailed path clearance conditions, both present and future, (2) possible tower height and construction restrictions, (3) potential radio interference, and (4) security requirements in the area.

4.2.31 Meteorological and Climatological Data

4.2.31.1 The climate of the area may suggest potential difficulty in site accessibility. As an example, the average and maximum snow depth in the area should be determined from climatological records. Note that there is a difference between snow depth and snowfall, the latter referring to the accumulated total if no melting or settling (packing) has occurred. There may be large differences in snow depths observed at a valley station and on an adjacent high ridge. Local farmers, ranchers, and forestry officials are good sources of information to supplement official weather service records. If deep snow accumulations at a site are infrequent, they may only rarely complicate operations or maintenance work at the site; but if snow normally accumulates to depths of several feet or more, special vehicles may be required for maintenance crews, and some allowances may have to be made in the placement of antennas and reflectors. Effects of snow loads on buildings should also be considered, and snow pack in front of an antenna can cause undesirable reflections and effectively reduce ground clearances.

4.2.31.2 In relatively flat country access problems may also arise because of rainfall, and good site drainage should be provided in the design. The site may become marshy or surrounded by water in some seasons. Consider possible effects of seasonal changes in the foliage of trees, and make necessary allowances for growth which may obstruct the radio path after several years.

4.2.31.3 Statistics on seasonal variations of maximum and minimum temperatures, humidity, and degree (heating) days form a basis for estimating required oil or gas storage space (for heating), as well as the need for air conditioning and dehumidifying. When air is cooled the relative humidity increases and vice versa; thus in polar regions relative humidity may drop to less than 5 percent when the normally dry outside air is heated and this can cause personnel discomfort and increase fire hazards.

4.2.31.4 The maximum winds to be expected should be determined for each site, rather than monthly or annual averages. Short-period peak gusts must be considered in the design of antennas and supporting structures. Wind speeds on isolated high hills or mountain peaks tend to be much higher than at sites on nearby plains, and high winds are also to be expected at lee-side valley and foothills sites near major mountain barriers.

4.2.31.5 An important factor to be considered in the design of antennas and towers is the possibility of ice storms (freezing rain), particularly if the peak ice load occurs during high winds. Extra bracing and additional guys may be required and heated radomes must be used.

4.2.31.6 Paths along or near the shore of seas or large lakes, or which cross large river valleys, are likely to have more propagation problems than paths farther inland or overland. Land and sea (or lake) breezes can produce strong temperature and humidity contrasts near the shoreline that can result in the fading problems described earlier. Air drainage effects and moisture concentrations in valleys can similarly lead to extreme variability in refractivity gradients which may result in undesirable propagation effects. Large irrigated areas in dry regions are also likely to have more extreme refractivity gradients than would ordinarily be expected in such a climate, because of the localized moisture contrasts which develop over and near irrigated areas [28].

4.2.31.7 The most extreme refractivity gradients occur when there is a relatively sharp interface between moist and dry layers of air. This condition, which is common in the trade wind pressure areas, forms a "cap" on the moist layer near the surface (over the ocean, or over semi-tropical land areas). Large moisture contrasts also occur where desert regions are adjacent to the sea. Similar contrasts may occur along weather fronts. The restriction on vertical mixing of the atmosphere caused by inversions of temperature favors the formation of strong refractivity gradients, and is the major reason that fading problems on overland paths tend to occur at night or in early morning.

4.2.31.8 Depending upon the frequency to be used on the proposed radio path, consider the effects of water vapor, clouds, fog, rain, and snow. Usually attenuation from these sources is not a limiting factor in path design below about 6 GHz, but at higher frequencies, paths may have to be shortened to obtain the desired overall reliability in areas of heavy s hewer - type rainfall. Attenuation from precipitation is related to the instantaneous intensity or rainfall rate, rather than total amounts, and statistics of monthly or annual precipitation totals are of little value in estimating the probable maximum attenuation. Rainfall intensity statistics are generally very limited, but useful information on the precipitation attenuation problem is contained in a number of publications [20, 29, 30, 4, and 19]. These data have been used as a basis for the attenuation estimates reflected in the earlier discussions (see figures 4.2-1 and 4.2-10 through 4.2-13).

4.2.32 Tower Height

4. 2.32.1 Self-supporting towers should be used except in a few rare cases of extreme heights. Tower construction is important for link design and route selection, since requirements for terrain clearance determine needed tower heights. As already noted in section 4.2.15, adequate tower heights for a link may be determined by plotting the beam path for k = 2/3 and superimposing this path on the terrain profile such that O. 6 first-Fresnel-zone clearance is achieved over the terrain object causing the greatest blockage. Generally, if the obstacle is near midpath, this fit should be made so that tower heights at each end of the path are equal. Note that if the obstacle is not in the center, a small elevation change at the site nearer the obstacle will have the same effect as a larger elevation change at the other end. Additional important questions to be considered are the type of tower that would be allowed at the site, possible hazards to aircraft, sufficient space, soil conditions suitable for support of the required tower, and the wind and ice loading conditions. For additional considerations, see section 4.4.4.

4.2.32.2 Except for over-water paths, a trade-off can often be considered between high towers on a long path and an additional active or passive repeater site. This may also require inputs from the field survey.

4.2.33 Radio Interference

4.2.33.1 Interference from unwanted signals may be classified as either external (from other systems or sources) or self-interference (within the system). The latter type can be controlled by good planning and equipment design, including route layout, since it is caused by equipment components within the proposed systerm, or overreach from adjacent or remote links due to unusual refractive index gradients. External interference (interference from other radio spectrum users) is most economically controlled in the planning stage by utilizing distance or terrain blockage for attenuating unwanted signals if their sources are known. Route selection is the most powerful tool for avoiding interference but frequency band selection may also be considered if there is a choice.

4.2.33.2 Overreach is self-interference caused by signals on the same frequency reaching one link from another in the same system. The scarcity of available spectrum space requires that an allocated frequency be used several times within one LOS system. If a ducting condition is present, links using the same frequency may be subject to mutual interference unless a combination of factors is sufficient to provide isolation between affected sites. Three of these factors are (1) the way the links along the route are staggered [4] (p. 21); (2) terrain blockage; and (3) choice of path orientation with antenna discrimination in the direction of the unwanted signal.

4.2.33.3 External interference, between 1 and 40 GHz, may come from any of several man-made sources such as harmonics from transmitters below 1 GHz, radar stations, or existing microwave communication systems. The tools for overcoming external interference are link orientation, distance, terrain blockage, antenna characteristics and polarization discrimin-ation, bandpass filters, and inter-organization consulting and cooperation. Possible sources of umwanted signals within 100 kilometers of each proposed site should be located and plotted on a map. The unwanted signals should then be investigated for potential interfering fundamental frequencies and harmonics, transmitter power, and antenna gain and polarization in the direction of the Pro-posed site. Care must also be exercised to assure that the proposed system will not interfere with existing radio facilities. In this regard, main beam inter-sections with satellite earth stations must also be avoided.

4.2.33.4 To ascertain the ambient RF environment, desk studies on electromagnetic compatibility (EMC) must be performed before firm site selection. These are requested throug command channels to the appropriate agency, having responsibility for the service-wide EMC program. Electromagnetic radiation field survey can be recommended by this EMC agency and should aLmost always be conducted for major communications terminals and for terminals recommended as a result of the desk study. Independently or perferably in conjunction with a field study, a theore-tical analysis by a center such as the DOD Electromagnetic Compatibility Analysis Center (ECAC), can provide valuable insight to the desirability of potential sites. Usually the responsible EMC agency personnel will make the arrangements to attain the ECAC assistance.

4.2.34 Site Security

4.2.34.1 In selecting routes, potential sites must be examined to determine how secure they can be made from theft, vandalism, conflict, or natural phenomena. In isolated areas, the cost of providing guard personnel and supporting facilities must be considered. Susceptibility to natural disaster may also be a major factor for overall reliability estimates. Natural phenomena which may cause outage are extremely high winds, icing conditions, flooding, and earthquakes.

4.2.35 Select Primary and Alternate Routes

4.2.35.1 On the basis of the information which has been gathered, tradeoff studies must be made between some individual sites, and also between some sections of the potential route to determine a primary and an alternate route. A few good alternate sites along these routes should also be selected for further investigation. Each site along the route will have to be visted and the results of the site survey further considered prior to making a final determination on the system route.

4.2.35.2 At this stage, the design worksheets and documents should be reviewed by additional qualified personnel in order to decrease the possibility of omitting important details. All information gathered so far should be carefully categorized and retained for future reference. Information on primary and alternate route should be included in the engineering implementation plan.

4.2.36 Path Loss Measurements

4.2.36.1 Long paths which must be used for the primary or alternate routes and whose profiles indicate a potential for severe fading because of terrain reflections or very small angles of atmospheric penetration should be considered for possible path loss measurements. A particular path may appear to be marginal and yet be essential to complete and otherwise desirable route. In this event, consideration should be given to making path loss measurements over a limited time period. It must not be forgotten that path testing is expensive, so is any alternative; the difference in cost between path testing and an acceptable alternative is the criterion. Furthermore, the ultimate cost of not testing a path, while not always obvious, can be very high, because it is expensive to correct poor or unworkable paths. These factors, possible alternatives, engineering judgment, and the excercise or common sense should enable the designer to make a decision on requirements for tests.

4.2.36.2 Objectives of path loss testing are generally to confirm the workability of the microwave path before installing permant towers. These will be further discussed in section 4.3.17. Because of the the reguired to prepare equipment and personnel for these measurements, and the early need of the results, the necessity of making path loss measurements should be determined as soon as possible. In making this decision, the cost, manpower requirements, possible alternatives, and the time factor must be considered in their relation to the desired reliability and transmission quality of the proposed system. These factors must then be balanced against the difference in cost between propagation tests and possible substitutes. If measurements are required, permission to operate a transmitter on the test frequency in that area should also be requested.

4.2.36.3 Two principal causes of system degradation are blocking of the radio beam because of inaduate terrain clearance, and signal cancellation or fading because of ground reflections. The presence or absence of blocking can be ascertained by obtaining accurate path profiles from the maps or by using one of the alternatives that will be discussed in section 4.3.16. It is not always easy to evaluate the possibility of ground reflections and their effects on certain paths, but is even more risky to discount the possibility of reflections. This will also be discussed further in section 4.3.17.

Section 4.3 FIELD SURVEY

4.3.1 General

from the map studies outlined in Chapter 4.2 should be checked by a field survey, and in some cases path loss tests may be helpful in verifying the basis for initial performance estimates. If the best available maps are several years old, there may be recent man-made obstructions or tree growth that can materially alter critical path clearances; and the most detailed topographic maps do not supply all the information needed for the final system design.

4.3.1.2 The field survey will require appropriate liaison with area commanders and/or local officials, property owners, and representatives of host countries. These negotiations should be started as soon as the preliminary selection of sites has been completed, so that permission to visit and work on the sites will be available to the survey team at the earliest possible date.

4.3.1.3 The procedures to be followed in the field and the scheduling of the surveys should be established in advance. Since no two paths or systems are quite the same, requirements are likely to vary from one design effort to the next. A satisfactory procedure in one country or climate may be unsuited to another area, and time available for design and implementation of the system is also an important factor. Usually, two surveys will be made, but in some cases, it may be necessary or desirable to perform all survey tasks on the same field trip.

4.3.1.4 The Defense Communications Agency (DCA) has published a "site survey data book for communications facilities" (DCA Circular 370-160-3,[105]). It is recommended that the survey party be familiar with this document.

4.3.2 Planning The Field Survey

4.3.2.1 A successful field survey requires careful planning, and the survey party should study the available data on each site and path before going into the field. Check lists should be prepared for each site and path, outlining the specific information needed in the final stages of the system design. Duplicate copies of system maps and path profiles should be obtained, as well as copies of topographic maps, county road maps, and information on the location of benchmarks. The location of the radio paths and critical points should be carefully plotted on all maps to be used in the field, and tie points established between the various maps (e. g. , between topographic and county road maps). The survey team should also make inquiry as to the availability of recent aerial photographs of the area to be surveyed. The location of points on the radio path when in rough, heavily forested, or undeveloped areas can be very difficult, and the more information available to the survey team, the better the possibility of an efficient and accurate survey.

4.3.2.2 Equipment required for the survey, such as altimeters, theodolites, radios, steel tapes, etc. should be examined and tested well in advance of each survey trip, and the use of equipment check lists is strongly recommended. Both delay of the project and personal embarrassment can result if, for example, one unpacks the theodolite at Site "X" and then discovers that the tripod is back at the home station.

4.3.2.3 Transportation and personnel requirements will vary with the type of area, time limitations, and the precision' of the survey. For example, helicopters may be required to reach certain obstacles inaccessible by road or trail. The party chief should have experience in microwave design and be familiar with the problems which may have been encountered in the preliminary design work on the specific system. The initial survey will require only a general knowledge of surveying principles, but the final (geodetic) site surveys must be made by well-trained and experienced surveyors.

4.3.2.4 On foreign surveys, the survey party should be provided with a contact who can provide them with descriptions of survey control markers, geodetic and/or local grid positions and/or elevations and accuracy of locally available topographic maps. It will be necessary to obtain clearances for U. S. Nationals (MILDEP) to perform surveys, and, if possible, arrangements should be made to have a local bilingual surveyor assist with the survey, at least to the extent of providing necessary liaison with property owners and assisting in location of control points. Clearance should also be obtained for use of electronic distance measuring equipment (such as the Electrotype and Geodimeter) and any communications equipment the team may plan to *use.*

4.3.2.5 The climate of the system area must be considered in long-range planning for field surveys. Very wet or snow-covered ground adds to the difficulty of the survey, e. g. , benchmarks and low reference points may be hidden. In remote areas clothing and shelter provided for the survey party must be adequate for the most severe weather possible in that area. Regular checking of current weather reports and forecasts while in the field can contribute to the efficiency and safety of the survey work, particularly in areas or seasons when sudden and severe changes in temperature, winds, or precipitation intensity are possible.

4.3.3 List Information Required

4.3.3.1 The leader of the system design study will be responsible for preparing a list of the information required which results from the field survey. There should be a separate list for each site and path, and each one should contain any information already available that may be of use by the survey team (e. g., owner of property on which proposed site is located, recommended access routes, etc.). (See worksheet 4.3-l). Specific points at which measurements are desired may be indicated on profile charts by arrows and appropriate notations.

4.3.3.2 The planned use of a particular site will determine the extent of the survey to some degree; thus, a passive repeater site, which need be visited only rarely after construction, may not require an all-year access that would be considered essential for an active repeater site. A manned terminal location may require on-site housing, water, sewage, and other facilities not necessary at repeater sites.

4.3.3.3 For unmanned sites, the following list indicates the type of information usually required from the field survey:

a. Precise location of permanent markers on the site. At least two permanent survey monuments should be placed on each site and the azimuth between them recorded; these should be located on a sketch and photograph. Geographical coordinates of the markers are required to ±1 second; elevation above sea level to ± 1.5 meters. To avoid confusion, all elevation data should be recorded with respect to mean sea level (msl).

b. If a tentative site layout plan has been provided, the antenna locations with respect to the site markers should be marked on the site map in terms of precise directions and distances. (See examples, figures 4. 3-1 and 4.3-2).

c. Full description of site. Include soil type, vegetation, existing structures, access requirements, leveling or grading requirements, drainage, etc. Use sketch to show distances to property lines, benchmarks, roads, etc.

Site Name and Number

Latitude__________ Longitude__________ (Degrees, Min, See)__________

Map reference (most detailed topographic)__________

Nearest town (postoffice)__________

Access route: (all year?)

Property owner; local contact:

Site sketch______ Site photograph______ General description__________

Reference baseline______ By Polaris________ Other__________

Antenna No.__________ True bearing__________

Ground elev. MSL________ Takeoff angle (beam centerline)______

Takeoff angles to 45° right and left of centerline__________
(Significant changes-in horizon)

Critical Points: (include horizon)

Distance________ Map elev.________ Survey elev.________

Tree height________ Required clearance________

Description:

Horizon sketch________ Horizon photograph________

Power availability:

a. Nearest transmission line________ b. Voltage________

c. Frequency________ d. Phase______ e. Operating utility________

Drinking water source________ Estimated depth to groundwater________

Sewage disposal______ Type and depth of soil on and near site________

Nearest airport________ railroad________ highway________

navigable river________

Worksheet 4. 3-1 Sample Checklist for Site Survey (page 1 of 2)

Local communications facilities: telephone____telegraph____radio____

Nearby radio transmitters________relay stations________

Other interference sources________________

Local transportation facilities: airlines________railroads________

truck________bus________

Warehouse and storage facilities________

Local suppliers (hardware, lumber, concrete, etc.)________

Local contractors________

Fuel sources (oil, gas, propane)________

Local housing accommodations: Temporary________permanent_______

Local military or civil contact________

Meteorological data from local sources: (averages for each month)

Maximum/minimum temperature (daily)________

Precipitation________ (Also extreme 1- and 24-hour)

Snow depth__________ (Also maximum for period of record)

Prevailing wind direction and speed________

Extreme wind gust and direction________

Dewpoint or relative humidity (mean diurnal change)__________

Worksheet 4. 3-1 Sample Checklist for Site Survey (page 2 of 2)

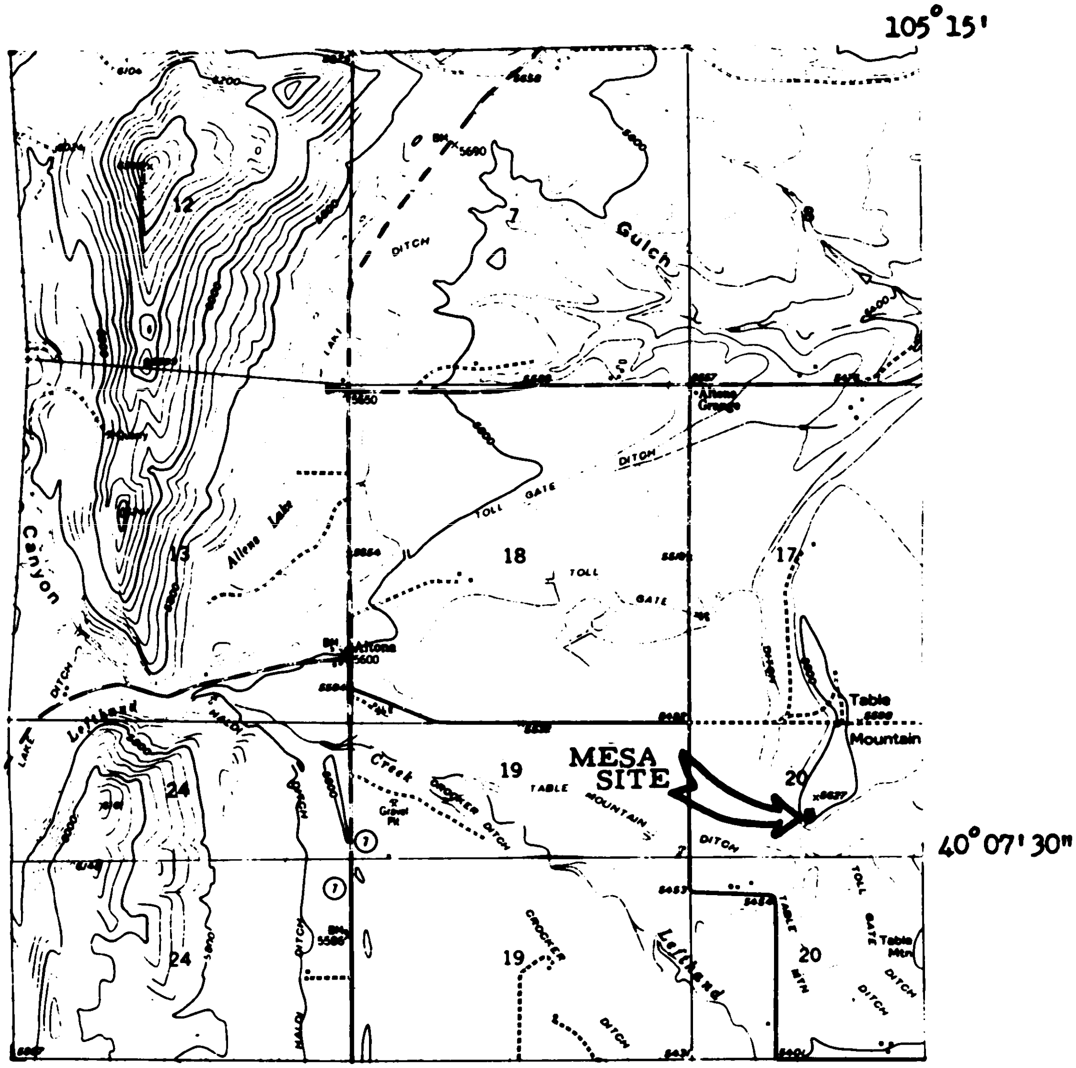


Figure 4. 3-1 Example of Topographic Map Section Showing “Mesa” Site (USGS Lyons, Colo. 7 1/2′ Quadrangle)

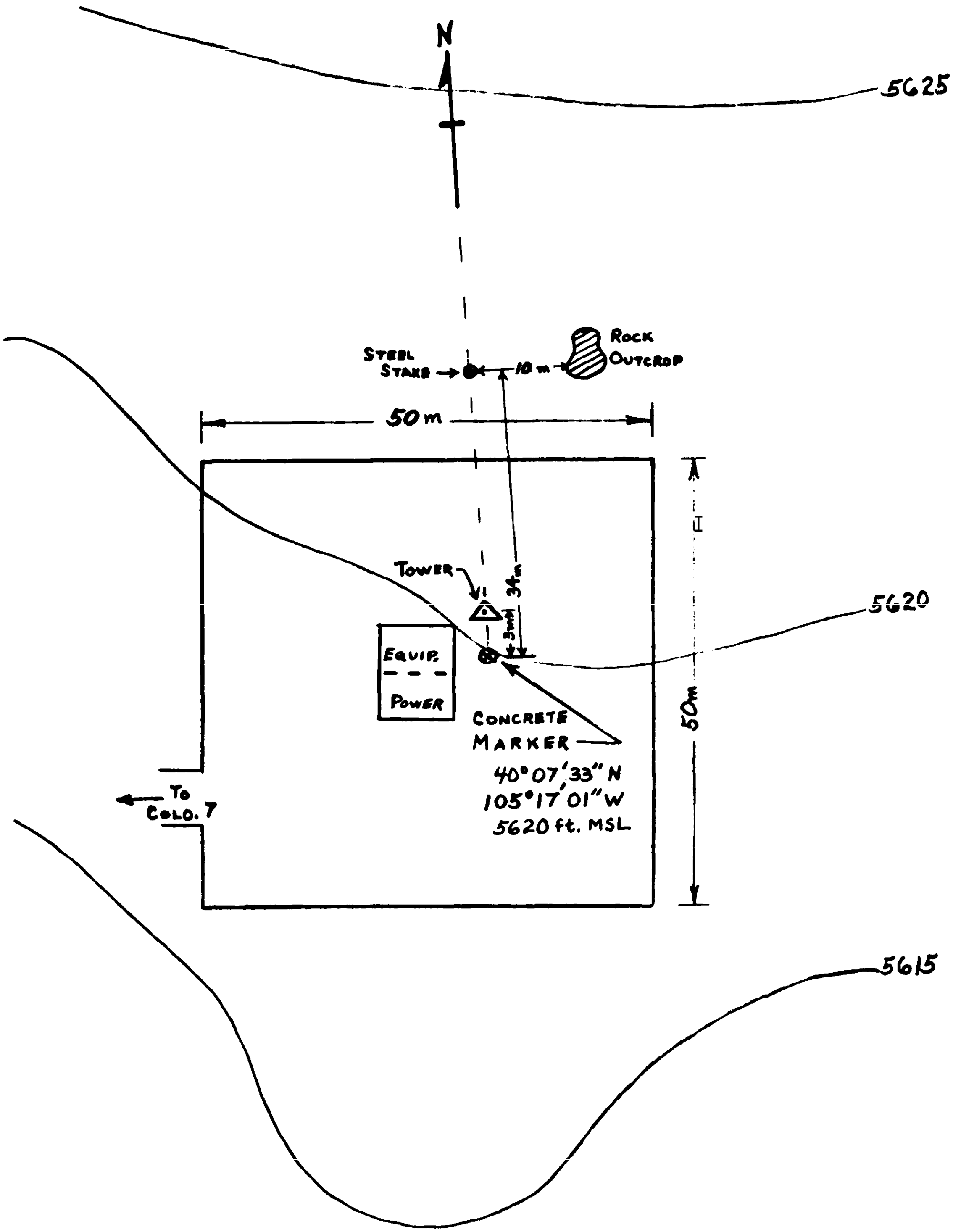


Figure 4.3-2 Example of Site Layout

A detailed topographic map of the site should be made (fig. 4.3-2). Use photographs to show closeup details, as well as general location with respect to surrounding large-scale terrain features. For manned sites, an estimate should be given of suitability with regard to water supply and sewage disposal -- consult local Well drillers, agricultural agents, plumbing contractors, nearby farmers or ranchers. On the initial site visit, general information on site location and access should be summarized on a form similar to worksheet 4.3.2. This will be useful in directing suppliers and contractors to the site.

d. Description of path. Give general description of terrain and vegetation as one proceeds along the path, if possible, from one site to the next; in particular, check elevations of ground and height of trees or buildings at critical points. Distances should be determined to an accuracy of ±0.1 mile (±0.2 km), azimuths to 1 minute of arc, elevations to $\pm 1^{o}$ from path centerline. At critical points, obtain elevations within a radius of about 30 meters. Show by sketch and photographs new construction or other features not correctly indicated by available topographic maps. Make sketches and photographs on path centerline from each site, and show azimuth angles to prominent features; also list elevation angles. (Example: "Repeater #2 to repeater #3; start survey at 0845 CST at BM #21A at site 2. Low rolling grass-covered hills near site, crossing Big Sandy Creek (20-ft wide)) at 6.8 miles; steeply rising terrain

DATE: June 6, 1972 **OBSERVER:** B. C. Carp

SITE NAME & NUMBER: MESA SITE # 1

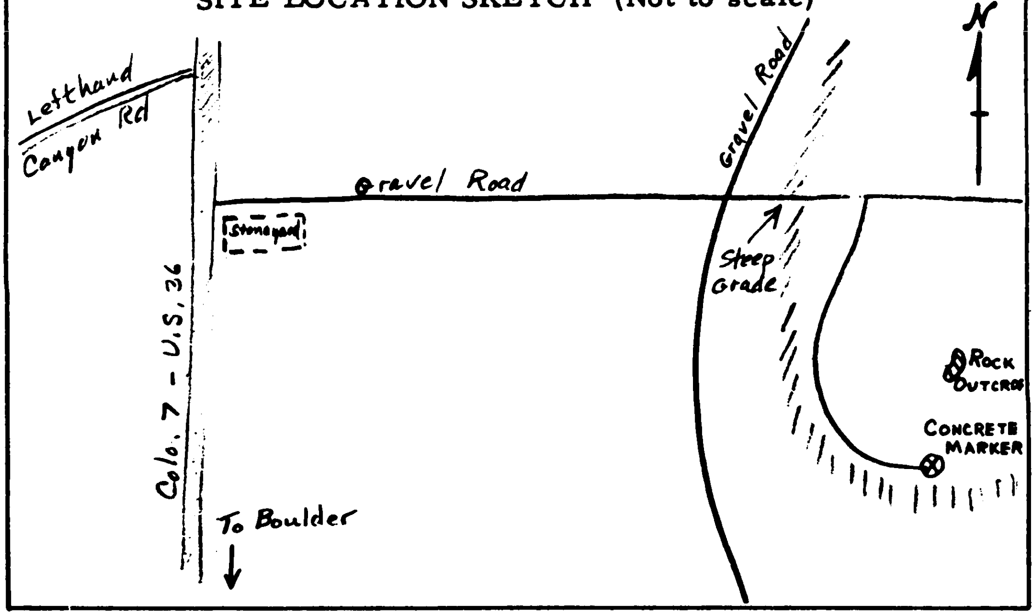
LOCATION: SE ¼ NW ¼ **Section** 20 **Town.** 2 **Range** 70 W
County Boulder **State** Colorado **Country** USA

REFERENCE MAPS: U.S.G.S. LYONS QUAD., 7½′, 1957

DESCRIPTION: Site is on south side of large flat-topped mesa (Table Mtn); covered with short grass, weeds, and few low bushes. No trees. Shallow sandy soil over gravel and rock; many small boulders on surface.

ACCESS ROUTE: From junction U.S. 36 and Broadway north of Boulder, go north on State 7 (U.S. 36) about 4 miles. After passing Beech Aircraft plant take gravel road to right just north of stoneyard (this is about ¼ miles S of Lefthand Canyon Rd.). Go east about 1½ miles to top of mesa, then take first road to right + go about ¼ mi SSW & then east to concrete marker.

SITE LOCATION SKETCH (Not to scale)



Worksheet 4. 3-2 Example of Site Information Worksheet

beyond creek. Critical point at 7.9 miles, profile shows 660 ft MSL, measured 672 ft by altimeter #2167 at 0910 CST 11-10-72. Trees on critical point ridge estimated 40 ft maximum by A bney level; beyond critical point to site 3 is rough pine-covered hills. 150 ft water tower nearing completion approximately 500 ft west of path and 0.5 mile from site 2".)

e. Power availability. Give location of nearest commercial transmission line with reference to each site; list name and address of utility firm; state voltages, phase, frequency, and main feeder size.

f. Fuel supply. List of local sources of propane, diesel fuel, heating oils, natural gas; also estimate of cost of item delivered to site.

g. Local materials and contractors. Determine if there are local sources of lumber and ready-mixed concrete; list names of local general contractors.

h. Local zoning restrictions. Make inquiry as to any that might affect use of site or height of antenna tower. Give distance from each site to nearest airport; determine if site is in a runway approach corridor.

i. Geologic and seismic data. Determine load- bearing qualities of soil at site, depth to rock and groundwater. Obtain soil samples if appropriate. Check with local authorities on the frequency and severity of seismic disturbances.

j. Weather data. General climatological data will have been assembled for the design studies, but local meteor-ologists can provide valuable supplemental details on the local variations of winds, temperatures, snow pack, precipitation, cloudiness, fog, etc. , with reference to hills, mountains, lakes, swamps, etc. , in the vicinity of the sites. Check at local military and civilian weather offices as to suitability of previous estimates for each site, including,

(1) average maximum and minimum temperature (monthly);

(2) average monthly precipitation, and extreme short-period totals (day, hour), days/month with rain;

(3) average wind direction and velocity, direction and velocity of peak gusts;

(4) average and extreme snow pack;

(5) flooding possibilities;

(6) occurrence of hurricanes, typhoons, tornadoes;

(7) persistence of fog or low cloudiness;

(8) probability of extended periods of very light winds;

(9) icing probability (freezing rain);

(10) average dewpoint temperature; diurnal variation of relative humidity.

k. Other microwave systems or radars. Indicate on map locations where "foreign" systems parallel or cross the proposed route; show approximate locations of the foreign repeater sites and name of operating agency. Show location of radars, and determine power, wave-length, and angle of coverage. To ascertain the ambient RF environment, electromagnet c radiation field surveys may be conducted (see paragraph 4.2.22.4).

k. Path loss data. These will only rarely be required; see section 4.3.18 for further discussion.

4.3.4 Survey Equipment Requirements

4.3.4.1 Equipment necessary for the field survey will vary with the demands of the design study, as well as with the type of terrain and climate. In remote areas backup units should be taken for all major equipment items, but this will not be necessary where supply depots are relatively near. Each survey. will need to be considered separately to assess the effects of loss of certain items of equipment.

4.3.4.2 Clothing, emergency shelter, and food supplies must be adequate for the most adverse conditions, allowing for the possibility of vehicle breakdown, road blockage, flooding, severe storms, etc. Climatological data obtained from military or civilian sources should be used in this planning.

4.3.4.3 Technical supplies and equipment will vary somewhat with the type of survey; the following items are recommended:

a. topographic maps, county road maps, path profiles, plan of proposed site,
b. benchmark information from U. S. G. S. or other sources,
c. surveyor's compass,
d. transit or theodolite (e.g., K & E or Wild) with laser light filter,
e. tripod and leveling rod,
f. sensitive altimeter (preferably three each; e.g., Wallace & Tiernan FA-181), with psychrometer kit,
g. hand level- clinometer (e. g., Abney),
h. steel surveyor's tape, 100 ft,
i. binoculars (7x35 or 8x50) with laser light filter,

j. surveying handbook, ephemeris for current year,

k. wooden stakes, hammer) stake bag, ax or hatchet,

l. Polaroid camera and ample film supply,

m. field notebooks, protractor, rulers, dividers, clip-boards, pencils, erasers, small hand tools, flash lights,

n. slide rule, small electronic calculator, math tables,

o. laser source with collimator, xenon strobotron light,

p. first-aid and snakebite kits,

q. several accurate watches; stop watch; small HF radio for monitoring standard time broadcasts,

r. one of the microwave distance measuring devices (e.g., electrotype or tellurometer). These devices may be adapted and calibrated for making certain types of path loss measurements.

4.3.4.4 Two-way portable radios are indispensible in path surveys, and also provide additional safety margin for work in remote areas or under severe weather conditions. On long trips a supply of spare batteries should be carried.

4.3.4.5 In areas with few benchmarks, a recording altimeter or micro barograph can be used to improve the accuracy of the survey.

4.3.4.6 If soil sampling is required, a shovel, auger, and sample containers should be included in the survey party supplies.

4.3.4.7 Path-loss measurements are not always required, but involve sizeable quantities of additional equipment. See section 4.3.17.

4. 3.5 Transportation

4.3.5.1 In areas with a good road network, a station wagon is a good choice for field survey transportation: tripods, leveling rods, and instruments are protected from sun and weather and are easily loaded and unloaded. In rough terrain, marshy areas, or where roads are poor, a 4-wheel drive vehicle is recommended. Most surveys will require at least two vehicles, and more will be necessary if the survey is to include path-loss testing. In some areas it may be more efficient to use a helicopter for site visits, particularly if sites are a long distance from roads.

4.3.6 Personnel

4.3.6.1 The survey party chief should be a member of the system design group who is familiar with the design objectives and has previous experience in field surveys. Other members of the party should be chosen on the basis of the particular needs of the survey; usually it will be advantageous to select individuals with varying backgrounds and skills if they are available. For example, various phases of most surveys can most suitably be performed by persons with experience in communications engineering, surveying, civil engineering, meteorology, and geology. Most tasks are such that more than one person is required. For final surveys, however, the survey party should include at least two well-trained and experienced surveyors. Where appropriate, the survey party may also include representatives of local commands, host countries, and contractors.

4.3.7 Frequency Requirements

4.3.7.1 If the path loss tests are to be performed, it will be necessary to obtain authorization for use of the desired frequencies on the particular paths. Permits may also be required for the mobile or portable 2-way radios, and for electronic distance-measuring equipment.

4.3.8 Time Requirements

4.3.8.1 The time required for the survey effort will include the time required to assemble and brief personnel, procure and test equipment, obtain permission for site visits, make the field measurements, and assemble the data in a form suitable for use in the final stages of the system design. Time estimates for field work should consider the nature of the terrain, quality of roads, and weather conditions that may be encountered. Ample time should be allowed for the site visits and path checks; accurate information from these tasks is of greater concern than early completion of the survey.

4.3.8.2 The path loss measurements team should be able to operate independently, i.e., the rest of the survey team should not be required to remain at a site or area while path loss measurements are in progress.

4.3.9 Request for Survey

4.3.9.1 The necessary requests for manpower and equipment should be initiated as soon as an estimate can be made of the completion date for the route alternatives study. Consideration should be given to climatic factors in areas where certain times of year are generally unsuitable for field work.

4.3.10 Obtain Permission for Site Visits

4.3.10.1 As soon as sites have been selected, brief descriptions of the sites should be prepared from the map data available, and pertinent information shown on accompanying sketch maps of each site. These descriptions should be forwarded to the appropriate military office with a request for site visit negotiations. The request should describe briefly the purpose of the proposed microwave system, approximate size of towers and buildings that may be necessary at each site, and should outline specifically what the survey party plans to do at the sites; e. g., set up theodolite, make distance and elevation measurements, mark tentative tower location and site boundaries with stakes, take soil samples (specify size), erect temporary tower for path loss tests, etc. If any permanent defacement of the property is planned (soil samples could be so considered) it should be plainly outlined in the proposal for visit. Size and type of vehicles to be operated on the site should also be given, as well as the maximum duration of the survey at each site, and the approximate calendar period in which the survey will be made.

4.3.10.2 A copy of the complete set of site visit authorizations must accompany the survey team. When a site is on private property, such as a farm or ranch, it is recommended that the survey party visit the owner or his tenant immediately prior to entering the site for the survey. Inquire as to preferred routes across the property (this may vary with crop development), movement of livestock, etc. This courtesy may influence later negotiations for lease or purchase of the site.

4.3.10.3 System design or field survey personnel will not ordinarily participate in site visit negotiations, but should be prepared to furnish a representative to accompany legal or property officers on visits to property owners. Negotiating officers should be thoroughly briefed on the purpose and general operation of the proposed system, so that they will be prepared to answer questions on possible effects such as interference to radio or TV reception, health hazards from radiation, etc.

4.3.10.4 If there is a short time schedule for implementation of the system, it may be desirable to proceed with land acquisition at the same time permission for site visits is being arranged, i. e., options for lease or purchase should be negotiated.

4.3.11 Site Visits

4.3.11.1 Upon arrival at a site, the first task of the survey team will be to verify the location selected on the basis of the map studies. There are likely to be small variations in the topography that were not shown on the maps, and it may be desirable, in the judgment of the" survey chief, to make small adjustments in the site location. The permanent site reference markers should then be placed and surveyed in. Next, the location of the antenna tower and buildings should be marked by stakes in accordance with the preliminary site plan. From the location of the tower and buildings, the boundaries of the desired plot of land should then be determined and marked by stakes, taking into consideration the tentative location of anchors for guyed towers if they are to be considered.

4.3.11.2 A sketch of the site is made in a field notebook, showing the location of the tower and buildings, trees, large boulders, ditches, etc. Then measurements are made with the steel tape, and recorded with dimension lines on the sketch, so that an accurate site map can be prepared. The sketch should be clearly identified by name, site number, geographical coordinates, and quadrangle map name or number. It should be accompanied by a verbal description of the type of soil, vegetation, number and size of trees (trunk diameter and height), number of trees that will have to be removed, approximate location and extent of leveling required. If soil samples are required, the sampling points should be marked on the site sketch.

4.3.11.3 Photographs are made of the horizon to the north, east, south, and west from the tower location, and also along the centerline of each path from the site; these should be fully identified and fastened to a page in the notebook. Use a transit or theodolite to determine azimuths of prominent features on the horizon of each photograph, and also indicate the elevation angle to prominent features of the path-centerline photographs. If possible, photographs should also be made at a short distance from the site to provide an overall view of the entire site; site boundaries and tower location should be entered on these in ink. A more distant view, to show the site area with reference to surrounding major terrain features, will also be useful.

4.3.11.4 Generally speaking, azimuths determined by magnetic compass are not sufficiently accurate for radio path surveys. When the compass is used for rough orientation, it should be corrected for the local declination, which may be obtained from topographic or aeronautical charts. There are, however, irregular or local variations of the compass bearings that are caused by magnetic storms, iron ore deposits, large objects of iron or steel, and electric power lines; therefore great caution must be used in checking site or path azimuths with a compass, particularly in the far north (e.g., Alaska, Iceland, Greenland) or in areas with known large mineral deposits. Azimuth references should be determined or confirmed by celestial observations if possible (see section 6.1).

4.3.11.5 The latitude and longitude of the tower location on the site should be determined to ±1 second. This can be done by map scaling, traverse survey, triangulation survey, and celestial observations. The method selected may vary with the particular conditions, such as irregular terrain and distance from a benchmark. In most cases this accuracy can be attained by careful scaling from a 7 1/2 minute quadrangle with a device such as the Gerber Variable Scale (one second of latitude = 101 ft or 31 meters, approximately). It will rarely be necessary to determine location by celestial observations, which require considerable time, highly skilled observers, and good instruments. The location should also be described with reference to nearby roads and cities so that contractors and suppliers can be readily directed to the site as indicated on the example in worksheet 4.3-2.

4.3.11.6 The elevation of the ground at the tower location should be determined to ±1.5 meters. The method used depends on field conditions, distance to benchmarks, personnel and equipment available, and type of survey. Differential leveling, or the extention of a known vertical control point (benchmark) by a series of instrument setups, is the most accurate method and is recommended for the final survey or when there is a benchmark close to the site. Trigonometric leveling is useful where elevations must be determined over relatively long distances, as in very irregular or inaccessible terrain; it is not ordinarily used for site surveys but may be employed to determine the elevation of obstacles along a radio path. Aerial photogrammetry and airborne profile recorders (radar or laser) can also be used, although these techniques tend to be quite expensive. Barometric leveling (or surveying altimetry) is the simplest method of determining relative ground elevations, and is particularly useful for initial surveys, although it can also provide the accuracy required for the final survey by careful use. Barometric techniques are treated in detail in section 4.3.13 and section 6.2.

4.3.11.7 For the initial survey, prepare a site sketch map similar to figure 4.3-2; include coordinates, location of prominent objects, elevation data, etc., using a scale on the order of 1" = 10 to 50 ft and contour intervals of 1 to 5 ft; it should show location of the reference baseline, nearby benchmarks, tower and building locations, etc. The preferred method of establishing the reference baseline is by celestial observations (see section 6.1).

4.3.11.8 The access to the site must be described in detail so that estimates can be made of the cost of building a road to the site. Prepare a sketch map showing the route of the proposed road with reference to the site and existing roads; also indicate the type of soil, number of trees that will probably have to be removed, degree of slope, and approximate length of the road (as compared to the most direct distance from the site to existing roads).

4.3.11.9 The probability of all-year access to the site should be estimated after discussing the matter with nearby residents, highway department maintenance personnel, and local meteorologists. Get an estimate of the number of days per year when existing roads in the area are impassable because of snow conditions or heavy rains. Inquire as to the possibility of snow removal and regular maintenance by highway department crews and equipment.

4.3.11.10 The availability of commercial electric power will be a major factor in determining the operating expenses of the site. If there is a nearby transmission line show its approximate route on a topographic or road map as well as recording pertinent details in the field notebook. Obtain the name and address of the utility company, and make inquiry as to the existing policy on line extensions for new customers. The survey party should have available information on the approximate power requirements of the repeater or terminal radio equipment, size and type of construction of the equipment buildings, and temperature to be maintained by air conditioning, so that utility officials can estimate the overall site power demands.

4.3.11.11 If the site is in an area where heating of the building will be necessary, determine if there are local sources of propane, natural gas, or heating oils. Also check on availability of fuel for the standby motor-generator. Determine approximate costs of these items, delivered to the site.

4.3.11.12 List nearest sources of building materials, such as lumber brick, concrete blocks, ready-mixed concretes List local general, electrical, and heating contractors.

4.3.11.13 Check with local authorities on possible zoning restrictions in the site areas regarding type of construction permitted, requirements for sanitary facilities, maximum height limitations, etc. Also check locations of nearby airports to see if proposed site is in the approach corridor of any of the runways.

4.3.11.14 Depending upon the nature of the proposed site, it may be necessary to check the depth of groundwater and bedrock and obtain a local opinion on the load-bearing qualities of the soil at the site. In some areas, it will be appropriate to check with local sources of information on the frequency and severity of seismic disturbances.

4.3.11.15 Weather conditions should be discussed with local meteorologists, as outlined in 4.3.3.3j.

4.3.11.16 The site visit also affords an opportunity to verify the existence, locations, and operational data of any other communications or radar terminals as noted in 4.3.303k.

4.3.11.17 Path loss testing is rarely required on LOS paths. If performed by a team independent of the survey party, it will be important that the exact locations selected for the antennas by the survey party be used in setting up antennas and towers for the path loss tests. Test procedures are further discussed in section 4.3.20.

4.3.11.18 Interference measurements may be required on some sites, depending upon what is already known or learned during the field survey about possible interference sources. Microwave repeaters should not be located less than 10 miles from a radar. If possible, terrain shielding of potential line-of-sight paths between the repeater and any radars up to 50 miles distance should exist under all conditions (even when ducting occurs). Interference may also result from other microwave systems that parallel or intersect the proposed system [4].

4.3.12 Survey Terrain Clearances

4.3.12.1 When the site visit tasks have been completed at both ends of a radio path, the terrain clearances should be checked, and other pertinent information on the path recorded. There will usually be only a few points on the radio path where clearance is critical, however, the entire path profile needs to be verified to some extent by the survey party. The maps available for design studies are frequently several years old, and recently constructed buildings, reservoirs, storage tanks, and roads may alter the map indications of clearances, reflection points, and site access. Any changes noted should be entered on the topographic maps, the terrain profile and in the field notebook; large structures should be photographed and the approximate dimensions shown on the photographs. A description of the terrain and vegetation, as one proceeds from one site to the other, is also entered in the field notebook (see example 4.3.3.3d).

4.3.12.2 Normally, conventional techniques involving differential leveling or precision altimetry will be used to check the terrain clearances. Other methods that may be useful in some circumstances include optical surveys (use of laser source, mirrors, and theodolites), airborne radar profile recorders, and three-dimensional aerial photography (photogrammetric techniques). The latter two tend to be relatively quick, but do not eliminate the need for site visits. In certain cases, however, they may provide information that could not readily be obtained by other methods.

4.3.12.3 The advantages and disadvantages of various terrain-checking techniques are as follows:

4.3.13 Profiles from Altimeter Surveys

4.3.13.1 Altimeter surveys are used to check elevations of critical points, especially in rough country or where existing maps are poor.

The type of terrain to be covered will have a direct bearing on the cost, accuracy and the time taken to complete the survey. Rugged, inaccessible country will make it very difficult to obtain good results, for the following reasons:

a. it is difficult to locate a point on the ground as being directly on the radio path. Hence, it must be assumed that the highest point in the immediate area will form the obstruction,

b. obstructions may be difficult to reach by parties on foot;

c. the accuracy of the survey depends largely on the time required to make comparative altimeter readings at different locations. The longer this interval, the greater the chance of a change in temperature or barometric pressure that could cause an error (see section 6.2). The use of helicopters can shorten these time intervals, from hours to minutes, particularly if the survey route requires scaling of difficult peaks. This saving in time can sometimes offset the expense of the helicopter, and this may even be more important on urgent jobs.

4.3.13.2 The methods of conducting altimeter surveys are covered in surveying textbooks [94, 96] and in the manuals distributed by makers of surveying altimeters. The accuracy obtainable is usually adequate if the survey is made by experienced personnel using good equipment.

4.3.13.3 Section 6.2 contains a summary of meteorological factors that can affect the accuracy of altimeter surveys, lists precautions to be observed in the use of altimeters, and describes techniques for using the altimeter on radio path surveys. Additional details can also be found in T.O. 31R5-1-9 [10].

4.3.14 Profiles from Optical Surveys

4.3.14.1 Optical methods of checking obstructions on radio paths are discussed in detail in section 6.3. Light from xenon tubes or sunlight from mirrors are used in conjunction with theodolites. These methods are used to measure the locations of obstructions as well as vertical angles to determine elevation differences. The discussion in section 6.3 includes an evaluation of the relative accuracy of the various methods, and numerical examples with sketches of the geometry involved.

4.3.15 Profiles from Aerial Surveys

4.3.15.1 Profiles can also be obtained by using a Terrain Profile Recorder (TPR) on aerial surveys of the proposed routes. The TPR system consists of a precision radar altimeter, a pressure sensing device called a hypsometer, and a continuous-strip 35 mm camera, which has been bore-sighted to the axis of the radar beam. The hypsometer measures the aircraft deviation from a preselected barometric altitude, while the radar altimeter measures the terrain clearance. The continuous-strip camera is set to take overlapping photographs to record the exact aircraft position; the recorded data include the tripping time of each exposure, the indication of the aircraft and radar altimeters, and the deviation shown by the hypsometer. A similar system employs a laser altimeter instead of the radar altimeter; however, this system has an operational limit of about 6000 ft, while the system with the radar altimeter can be employed from about 6000 to 32000 ft.

4.3.15.2 Path profiles can be obtained quickly by aerial methods, but there are a number of potential sources of error. These include the following:

a. Determination of the radio path center line -- the pilot needs markers and checkpoints, but these may be difficult to provide in rugged or inaccessible terrain, and may be of questionable accuracy if available maps are poor.

b. Beamwidth -- the radar beamwidth will vary from 100 to 500 ft at the surface, depending upon the altitude of the aircraft. Since the recorded signal corresponds to the high point in this strip, the indicated elevation of the radio path could be considerably in error in rough terrain.

c. The radar beam penetrates foliage of trees to a variable and unknown degree.

d. The effects of thermal or mechanical turbulence and wind drift make it difficult to hold a precise course and altitude, and any tilt of the radar beam causes errors in the "on-course" elevations.

e. General errors in pressure altimetry are discussed in section 6.2. These include instrumental lag, temperature errors, and errors related to movement of pressure systems. Sizeable errors may occur in the vicinity of thunderstorms, where "pressure jumps" frequently occur. In addition, there are errors related to the static pressure system of aircraft altimeters.

4.3.16 Profiles from New Maps Drawn from Aerial Photographs

4.3.16.1 Profiles may be obtained from maps based on three-dimensional aerial photographs, using photogrammetric techniques. Very high accuracy is possible if a sufficient number of precise ground control points are used. A series of photographs is made of the desired area from altitudes between about 300 m and 10,000 m, depending on the scale and accuracy required. Each photograph has a 60% overlap with adjacent photographs, and a set of two adjacent pictures forms a “stereo pair” that gives a three-dimensional model of the terrain, when seen through a special viewer/plotter device. This has a measuring system for determining horizontal and vertical distances from the projected model by reference to the photo control points previously surveyed and marked on the ground. Auxiliary equipment can be set to trace a particular elevation and plot the contour lines over the area to the desired interval.

4.3.16.2 The comparative cost of this method and more conventional techniques of preparing path profiles is not known at present. It is doubtful if photogrammetric methods would be economically feasible for single links, but for an extensive system the costs should be more competitive. If recent photographs are available, photogrammetric techniques may provide much more current path information than could be obtained from the best available topographic charts, which may be several years old, and may not show recent changes on the radio path that could significantly influence path performance such as new construction, or perhaps the highly reflecting surface of a new reservoir. Interpretation of the stereo photographs by experts can also provide information on the type, height, and density of trees, as well as the best location for access roads, sources of water supply, location of power lines, and sources of possible interference.

4.3.17 Path Loss Measurements

4.3.17.1 Path loss tests, if required, are made by transmitting an unmodulated RF carrier between adjacent repeater sites and measuring the received power levels over a period of time and in some cases for various combinations of antenna elevations. Path loss as a function of time and antenna height is readily determined from such data if transmitter power, antenna gains, and waveguide losses are known.

4.3.17.2 Path loss measurements are not usually necessary on carefully designed LOS radio links. There are paths, however, where it may be advisable to make such tests prior to facility construction. If, for example, antennas of the heavy horn-reflector type are to be used, the antenna position on the tower cannot easily be changed once the installation is completed. In such cases height-gain measurements may help in determining the optimum antenna position. Measurements are also recommended on any path where there is a possibility of strong ground reflections, or on paths where design calculations indicate borderline conditions of fading margin or Fresnel-zone clearance (see section 4.2). These problems might arise where the choice of suitable sites is limited, or local zoning restricts tower heights (near airports, as an example).

4.3.17.3 Manpower and equipment required for path loss testing make it an expensive operation. Temporary towers are usually required at both sites as are some means of moving the antenna quickly from one position on the tower to another (a clamp-on track is sometimes used). Portable power units will also be needed, in addition to a stable transmitter and receiver, recording equipment, transmission lines, and calibration equipment. The tests must be made over exactly the same path as that intended for the final installation, and in rough or heavily wooded terrain it may be nearly impossible to make measurements until the sites have been acquired, ground cleared, and access roads provided.

4.3.17.4 Section 6.4 contains more detailed information on the desirable equipment and tower characteristics for path loss testing, as well as suggestions relative to calibrations and operational procedures.

4.3.18 Objectives of Path Loss Tests.

4.3.18.1 Since the performance of path loss tests may become quite expensive and require a substantial amount of time, a careful analysis of test objectives must be made before a field effort is mounted. Such an analysis is logically based on the results of the preliminary design work described in section 4.2 (Study of Route Alternatives). In general, path loss tests on line-of-sight links may have the following objectives:

a. Verification of line-of-sight conditions over a specific link,

b. to provide a basis for selecting optimum antenna heights,

c. evaluation of potential fading phenomena, and basis for selecting antenna spacings for diversity operation.

4.3.18.2 Since line-of-sight systems are usually designed with adequate terrain clearance, as discussed in section 4.2, verification of line-of-sight conditions by path loss measurements may only be required on long links where the information from available maps is not reliable, and optical methods cannot be employed. Other considerations and procedures to achieve the three objectives will be discussed in the following paragraphs.

4.3.19 Antenna Height Gain, Lobing, and Atmospheric Effects.

4.3.19.1 If we assume a link over relatively smooth ground where a single specular reflection can be obtained, the relative phase of the direct and the ground-reflected component changes with antenna height and produces alternative addition and cancellation in the resultant field at the antenna. Starting with heights corresponding to grazing, the resultant field will first rise rapidly to a maximum with increasing antenna height, and then will go through a series of "lobes" (i.e., the successive maxima and minima) when the height is increased further. These lobes become smaller with increasing antenna height; i.e., the maxima and minima are closer and closer together until they are no more distinguishable because of the integrating effect of the antenna aperture. The spacing between maxima and minima is also a function of carrier frequency.

4.3.19.2 The lobing pattern as a function of height for the case just discussed will also change as a function of changes in the atmospheric refractivity gradient, and complex patterns may result from a sharply stratified atmosphere which may produce atmospheric multipath components in addition to the ground-reflections previously discussed.

4.3.19.3 If there are no ground reflections, no lobing pattern will be observed and the received field will rise with antenna height to the free-space value and remain essentially constant for further height increases. Such a condition will usually exist in practice where the terrain is sufficiently irregular to prevent specular reflections, particularly at higher microwave frequencies. Occasionally, multiple specular ground reflections will occur and may complicate the lobing pattern in a manner similar to atmospheric multipath.

4.3.20 Verification of Line-of-Sight Conditions.

4.3.20.1 Based on the discussion in paragraph 4.3.17.3 above, the existence of line-of-sight conditions can be quickly verified, if required, by measuring the received power over a specific link for a short time, and comparing the measured level to that corresponding to free-spice propagation conditions. This should be done preferably at times when the atmosphere is well-mixed so that effects of stratification do not appear. Considering atmospheric absorption over the path (see section 4.2.22) and possible calibration errors, the received power level over line-of-sight links up to about 50 km in length should be within a few decibels of the free-space value.

4.3.20.2 If the test antenna at one of the terminals can be raised and lowered, an assessment of potential fading conditions can be made in many cases. If a substantial lobing pattern exists even under conditions of a well-mixed “standard” atmosphere, multipath propagation by reflections from terrain can be assumed to exist. Since the lobing pattern, as already noted, changes with atmospheric characteristics, substantial fading can be expected, and the use of diversity operation over the link should be considered.

4.3.20.3 A recent CCIT Handbook ([12], see appendix to section B.IV.3, section 14) includes suggested test procedures to determine the location of obstructions and values of the effective earth radius factor, k, from path loss measurements. However, these procedures are largely based on idealized terrain and atmospheric conditions; e.g., specular reflections from well-defined portions of the terrain along the path, and a well-mixed atmosphere with refractivity gradients which may be time-varying, but are constant over the volume of the propagation path at any particular time. Consequently, it is not likely that such tests will produce unique results in a cost-effective manner.

4.3.21 Selecting Optimum Antenna Heights by Path Loss Tests.

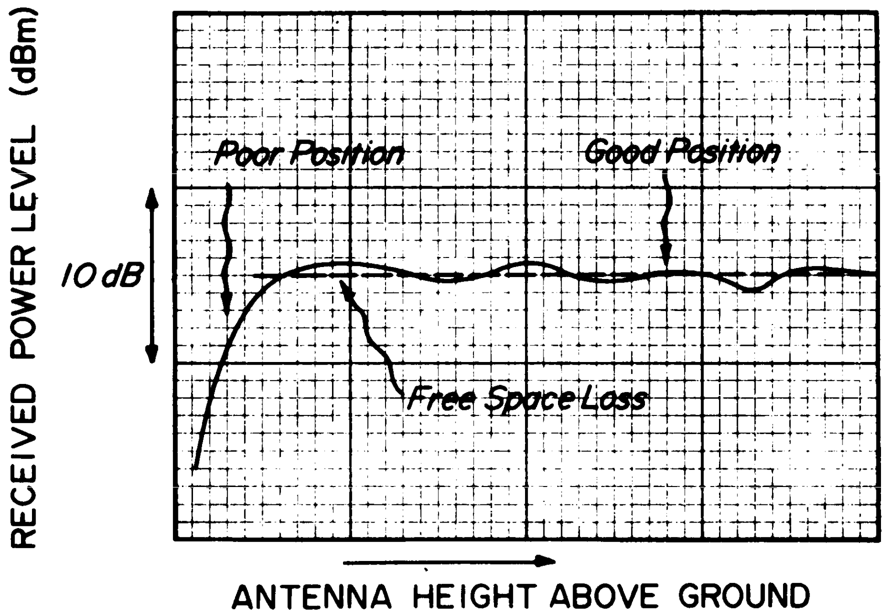
4.3.21.1 Raising and lowering an antenna may prove or disprove the existence of a lobing pattern for the specific atmospheric conditions existing at the time of the tests, but it should not be attempted to fix or recommend a particular antenna height on the basis of a short-term test. This is particularly applicable to cases where the frequency for path loss tests is not the same as that which will be ultimately used for the system, since the lobing pattern is frequency-dependent.

4.3.21.2 If antenna heights must be determined or verified by path loss tests over a short time period, they should be selected in the middle of a height interval within which the received field is close to the free-space value and constant within a few decibels. This will provide some assurance that day-to-day changes in the average atmospheric refractivity will have no appreciable effects on the received radio frequency power.

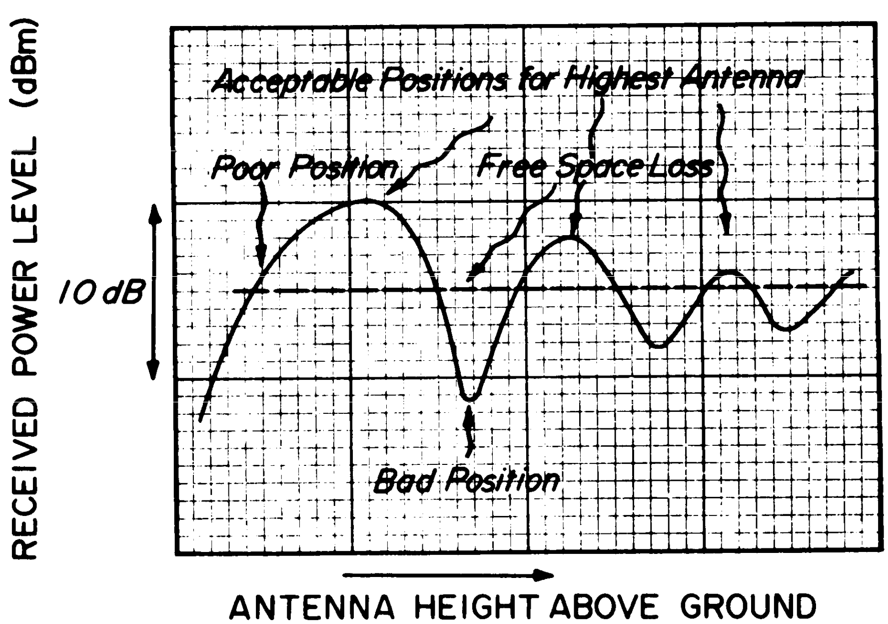
4.3.21.3 Positioning the antenna within a height region where the received field varies rapidly with height should be avoided. A monotonic increase in field of tens of decibels over antenna height increases of several meters is a good indication that the path is close to grazing and may be subject to blocking and resulting power fading during subrefractive conditions (see section 4.4.11). Figure 4.3-3 is a pictorial representation of possible field strength variations with antenna height for a well-mixed atmosphere, and includes suggestions for “good” and “bad” antenna positions. However, greater confidence in determining antenna position can only be obtained from a combination of careful analysis of path geometry and available refractivity data with long-term simultaneous measurements at several heights. Such a procedure is usually too expensive in relation to benefits derived for most practical microwave links.

4.3.22 Evaluation of Fading Phenomena and Diversity Design.

4.3.22.1 There are systems and links where it is not possible for a number of reasons to employ sufficient antenna heights to provide adequate terrain clearance, or where paths are exceptionally long, or where climatological conditions are conducive to severe fading.



(a) no lobing pattern



(b) lobing pattern

Figure 4.3-3 Example of field strength variations with antenna height for a well-mixed atmosphere.

Examples are primarily paths over water with limited tower heights. Since it has not yet been possible to deduce statistics of the expected received power levels from a limited knowledge of the statistics of atmospheric characteristics, it may in some cases be useful to perform path loss measurements over an extended period of time in order to obtain more confidence in the performance predictions, or even to avoid costly overdesign.

4.3.22.2 Path loss tests under such circumstances may be performed using the equipment installed and operating on the basis of best available design estimates in accordance with the material in sections 4.2 and 4.4. However, the results of the tests may indicate desired changes in the equipments antenna positions, and diversity design. It will usually be advantageous to select periods for path loss tests when severe fading is anticipated.

4.3.22.3 Available meteorological data should be consulted to determine diurnal and seasonal periods when atmospheric stratification and ducting is likely to exist. As an example, this may correspond to summer nights for paths over flat terrain in a temperate zone. For overwater links, or links in coastal areas, the possibility of changes in refractivity gradients related to seasonal shifts in the prevailing wind flow should be considered. In one season the air flow may bring warm, dry air from the land over the sea (a condition frequently causing radio ducts), while in another season the flow may be predominantly from sea to land. On the basis of such qualitative analyses the best season and suitable daily schedules for path loss measurements can be determined.

4.3.22.4 Simple criteria regarding diversity design (i.e., spacing of antennas, or frequency separation) have been given in section 4.4.24. However, these criteria may not be applicable in cases where pronounced lobing patterns due to specular reflections from the ground exist, and where strong atmospheric stratification can be expected during a large percentage of the time. Dougherty [35] has shown methods to determine antenna separations in space, or frequency separations which assure that the two channels of a diversity system would not be subject to simultaneous fading for a wide range of possible refractivity gradients. Path loss tests over a longer time period can be used effectively to verify the usefulness of configurations determined in this manner from theoretical considerations. A discussion of applicable measurement results for a long line-of-sight link in moderately rolling country has been presented in [97].

4.3.23 Utilization of Survey and Measurement Data.

4.3.23.1 On conclusion of the field observations, the survey data should be summarized for use in the final system design studies. Most of the analysis and summarization of field data is best done while the survey is in progress, since omissions or discrepancies noted can then be readily checked while the survey party is still in the area. Site maps should be prepared for each site, showing locations of antennas, access roads, etc. Significant discrepancies between the original path and site data should be listed, and corrections shown on path profiles and topographic maps. A n information folder should be prepared for each site, containing maps and all other pertinent informstion, such as land ownership, power availability and cost, climatic data, zoning restrictions, etc.

4.3.23.2 If path loss measurements were made, the records should be analyzed and height-gain graphs plotted when applicable. Long-term records should be carefully analyzed to obtain statistical information regarding power levels, fading frequency and depth, and diversity improvement.

4.3.23.3 In using the various data collected by the survey party, technical desirability must be weighed against site availability, cost of leasing or purchasing land, site preparation and road access costs, fuel and power costs, and all-year accessibility. Security considerations may also become important in certain areas.

4.3.23.4 Requests forwarded to area commands for approval of sites should be accompanied by maps and other detailed information, such as legal description of the property, name and address of owner or legal representative (see also worksheet 4.3.2).

Section 4.4 LINK DESIGN.

4.4.1 General

4.4.1.1 Using Section 4.1, certain basic information about the system was obtained: its geographic location, channel requirements, and its location in the spectrum.

4.4.1.2 Section 4.2 described selection of potential sites and routes, and how to systematically grade the site and route alternatives in order to select the more desirable ones for additional investigation with site surveys.

4.4.1.3 Section 4.3 described methods of obtaining complete and accurate information needed for final selection of links and for providing detailed, accurate path profiles and site layouts. In addition, explicit information about potential interference sources was obtained.

4.4.1.4 With this knowledge, we can proceed now in Section 4.4 to describe how to check, analyze, and summarize the information described in 4.1,4.2, and 4.3 and finally, we will consider how to make a preliminary selection of equipment types and sizes for a stated performance of each link in terms of median voice channel signal-to-noise ratio. The discussion on adjustments of link design resulting from system noise performance estimates will be presented in Section 4.5 (see figure 4.5-14). The required median signal-to-noise ratio for each link may be obtained from appropriate DCA standards that are current at the time and the communication traffic requirements information described in Section 4.1. Section 4.4 includes background information on propagation effects with emphasis on fading mechanisms. It is organized as follows (see also figure 1-4):

a. Path profile upgrading and checking (sect.4.4.3).

b. Calculating tower heights (sect. 4.4.4).

c. Propagation (sect. 4.4.5 through 4.4.21).

d. Diversity (sect. 4.4.22 through 4.4.25).

e. Radio frequency interference (sect. 4.4.26 through 4.4.27).

f. Equipment considerations (sect. 4.4.28 through 4.4.46).

4.4.2 The link design estimate

4.4.2.1 The worksheets in section 4.4.3 are used for summarizing the results of the initial estimates of the link design as demonstrated by the example. Because of the prodigious number of equipment options, the large range of terrain and climate conditions, and the variety of interference environments, no attempt has been made to provide a totally self-contained set of link design worksheets in section 4.4. Final selection of equipment types and sizes will be discussed in section 4.5

4.4.2.2 The basic link design information should be documented on works beets 4.4-1 through 4.4-5 as shown by the example given here and also in section 4.5.41. Reference is made on these worksheets to the various sections of the handbook that will be helpful for obtaining desired pieces of information. The last result on worksheet 4.4-5 (step 44) is the expected median receiver input power, in dBm. As a first estimate, this value P_r is sufficient if it exceeds the sum of the required median carrier-to-noise ratio (in dB) and the receiver thermal noise threshold (usually in dB). The latter is the sum of the thermal noise level 10 log(kTB_{IF}) (usually in dBm) and the receiver noise figure F in dB. These terms are further defined in par. 4.5.27.2; it will suffice for the present to state that the thermal noise level in dB can be expressed by(-174 + 10 log B_{IF}) where the intermediate frequency bandwidth B_{IF} is in Hertz. Figure 4.4-1 is a example of required values of receiver input power

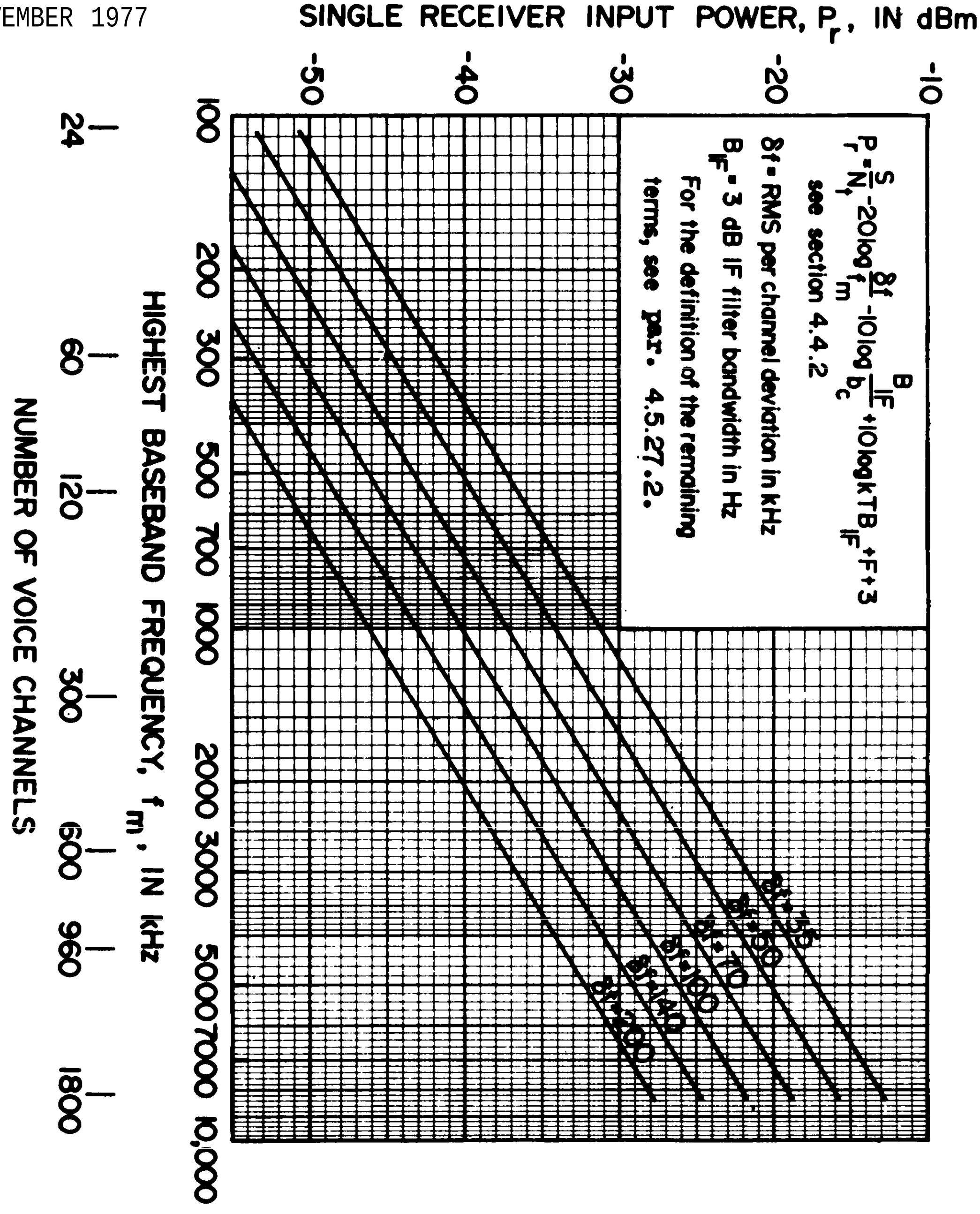


Figure 4.4-1 Required median receiver input power as a function of RMS per channel deviation and highest baseband frequency.

for an FDM/FM system based on currently applicable DCS Standards [98], and may be used for this purpose. The curves in this figure are based on the equation given in the legend; this is equation (4.5-10) solved for P_r with a 3 dB term added to offset equipment noise. The IF filter bandwidth B_{IF} is assumed to be equal to the radio frequency bandwidth b_{rf}. For this example, the required value of the voice channel signal-to-thermal noise ratio, S/N_t, is assumed to be 66 dB and the receiver noise figure is 10 dB. At the median value P_r of receiver input power, equipment noise will probably be a substantial factor in determining the voice channel signal-to-noise ratio; this is the reason for the added 3 dB term as noted above.

4.4.3 Path profile upgrading and checking

4.4.3.1 In the initial stages of the design a path profile of the link should have been plotted in accordance" with Section 4.2.15 and figure 4.2-4. Now, corrections corresponding to the information obtained from the site survey should be incorporated into the profile, and it should be checked to see if it contains the following pieces of information:

a. Check the validity of the site coordinates marked on the map from which the profile was plotted with those obtained during the site survey.

b. The height above mean sea level of the terminal points on the profile should agree with the heights measured in accordance with Section 4.3.11, and as shown for the tower base height in figure 4.3-2.

C. The photographs taken in accordance with Section 4.3.11 should be checked for down-path clearance in the immediate foreground, and the elevation angle to the horizon indicated by the geometry of the profile should be checked against the measured elevation angle down-path.

d. If there are trees or buildings at the site and on or near the center line down-path, make sure their heights and locations are shown on the profile. For trees, an allowance for growth should be indicated as shown in the example on Worksheet 4.4-1.

e. Indicate any local restrictions on tower heights on the profile. If the antenna tower already exists on site, indicate at what heights antennas can be placed.

f. Check that the results of the terrain clearance survey described in Section 4.3.12 are incorporated in the profile.

g. Make sure that potential specular reflectors mentioned in the site survey data or shown on the map (such as bodies of water which lie along the path) are noted on the profile.

h. Make a check of the height of critical points along the profile for agreement with the corresponding points on the map used for the plotting of the profile.

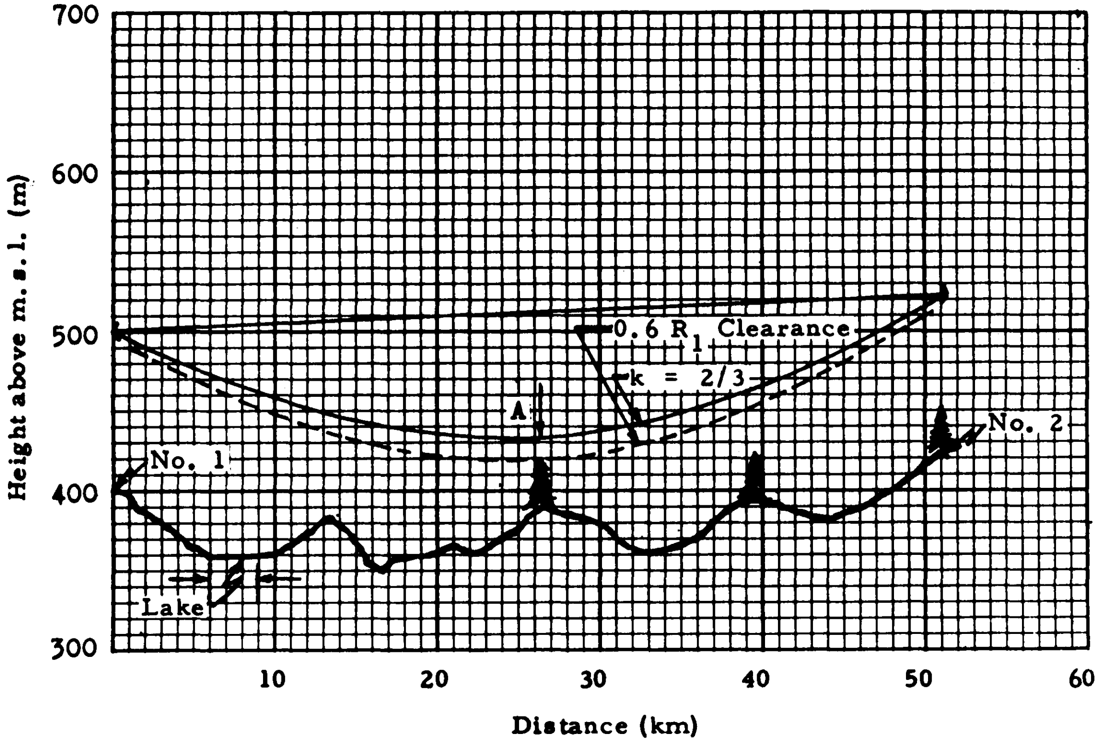
4.4.3.2 If during the site survey enough information was obtained on local weather data to estimate the range of refractive index gradients, indicate this range on the profile (see also paragraph4.4.5.1)

4.4.3.3 Worksheets

The worksheets in this section show how to organize the terrain profile and equipment information for an individual line-of-sight link, so that design parameters can easily be summarized and tabulated. An appropriate example is started on worksheet 4.4-1, 4.4-2 and 4.4-3; the complete link design calcula-ions for this example are given on the filled-in worksheets in section 4.5.41

Site Identification

From Volmer (Name), No. 1 (Abbrev.) to Lyons (Name), No. 2 (Abbrev.)



Notes:

1. A 30 percent allowance for grouth has been included in the tree heights shown on the profile.
2. The worst estimate of sub-refractive gradients for this area is +39 N units/km corresponding to a value of k=0.8 (Fig. 4.4-4)
3. The take-off angle, , at site No. 1 is determined by Eq. 4.2-4. Since for k=4/3 (a=8493 km), $(h_2-d^2/2a)$ is less than h_1, the angle of penetration of potential layers at some location along the path will be zero.

Worksheet 4.4-l Link Design Profile (Example)

Calculate h, the displacement of the curved earth radio path from the flat earth path (section 4.2.15).

$h = \frac{d_1 d_2}{12.75k}$ where h is in m and d_1 and d_2 in km. Calculate the distance from the center line of the radio beam which will provide 0.6 of first Fresnel zone clearance, 0.6 R_1 (section 4.2.18).

$$0.6\ R_1 = (0.6)\ (17.3) \sqrt{\frac{1}{f_{GHz}} \quad \frac{d_1 d_2}{d_1 + d_2}}$$

For k = 2/3 and f = 8 GHz,

$h = 0.118\ d_1 d_2$ and $0.6\ R_1 = 0.512\ \sqrt{d_1 d_2}$.

d_1 (km)	d_2 (km)	$d_1 d_2$	h (m)	$\sqrt{d_1 d_2}$	$0.6R_1$ (m)
5	46.3	231.5	27.32	15.22	7.79
10	41.3	413.0	48.73	20.32	10.40
15	36.3	544.5	64.25	23.34	11.95
20	31.3	626.0	73.87	25.02	12.81
25	26.3	657.5	77.59	25.64	13.13
30	21.3	639.0	75.40	25.28	12.94
35	16.3	570.5	67.32	23.89	12.23
40	11.3	452.0	53.34	21.26	10.89
45	6.3	283.5	33.45	16.84	8.62
50	1.3	65.0	7.67	8.06	4.13

Worksheet 4.4-2 Link Design Clearance Calculations (Example)

A. Distance on Profile 26.3 km.

Ground Elevation *390* m above m.s.l.

Tree or Obstacle Height 30 m above ground.

Total Obstruction Height 420 m above m.s.l.

For an assumed upper antenna height of 100 m & 100 m, clearance of 13.6 m is realized for "k" = 2/3 (worst case). This provides 0.6 (fraction) of First (order) Fresnel Zone clearance for this "k" value.

B. Distance on Profile ____________ km.

G round Elevation ____________ m above m.s.l.

Tree or Obstacle Height ____________ m above ground.

Total Obstruction Height ____________ m above m.s.l.

For an assumed upper antenna height of ____________ m, clearance of ____________ m is realized for "k" = ____________ (worst case). This provides ____________ (fraction) of ____________ (order) Fresnel Zone clearance for this "k" value.

C. Distance on Profile ____________ km.

Ground Elevation ____________ m above m.s.l.

Tree or Obstacle Height ____________ m above ground.

Total Obstruction Height ____________ m above m.s.l.

For an assumed upper antenna height of ____________ m, clearance of ____________ m is realized for "k" = ____________ (worst case). This provides ____________ (fraction) of ____________ (order) Fresnel Zone clearance for this "k" value.

Worksheet 4.4-3 Link Design Clearance Check (Example)

Site Identification

(1) ____________ (Name), ____________ (Abbreviation)	(2) ____________ (Name), ____________ (Abbreviation)

Site Location and Physical parameters

(3) Latitude _ _ - _	(4) Latitude _ _ _ _	sec. 4.4.3
(5) Longitude _ _ _ _	(6) Longitude _ _ _ _	sec. 4.4.3
(7) Altitude above mean sea level ________m.	(8) Altitude above mean sea level ________m.	sec. 4.4.3
(9) UTM Coord. ____________	(10) UTM Coord. ____________	sec. 4.2.14.
(11) Azimuth to (2), _ _ _ True	(12) Azimuth to (l), _ _ _ True	sec. 4.2.16
(13) Proposed upper antenna height above (7), ________m.	(14) Proposed upper antenna height above (8), ________m.	Worksheet 4.4-1
(15 Proposed vertical diversity antenna separation from (13), ________m.	(16 Proposed vertical diversity antenna separation from (14), ________m.	sec. 4.4.24
(17) Proposed antenna type, ____________	(18) Proposed antenna type, ____________	
(19) Size ______ft, ________m	(20) Size ______ft, ________m	fig. 4.4-33
(21) Expected antenna gain _____dB above isotropic	(22) Expected antenna gain _____dB above isotropic	fig. 4.4-30
(23) Design center carrier frequency ________GHz .	(24) Receiver noise threshold $-174 + 10 \log B_{IF} + F$ ______dBm.	par •4.4.2.2

Worksheet 4.4-4. Link Design Summary, Part 1

(25) Required waveguide length, ______m.	(26) Required waveguide length, ______m.	Worksheet 4.4-1 (for tower heights)
(27) Proposed waveguide type ______	(28) Proposed waveguide type ______	sec. 4.4.40
(29) Waveguide loss per standard length dB per ______m	(30) Waveguide loss per standard length ____dB per______m	fig. 4.4-43
(31) Waveguide loss A_{tl} ____dB (including connectors)	(32) Waveguide loss A_{tl} ____db (including connectors)	fig. 4.4-43
(33) Circulator and/or Diplexer Losses A_c Transmit______dB	(34) Circulator and/or Diplexer Losses A_c Receive ______dB	par. 4.4.43.1
(35) Isolator Losses A: Transmit ______dB	(36) Isolator Losses A: Receive ______dB	

(37) Net fixed losses, (31) + (32) + (33) + (34) + (35) + (36), ______dB.

(38) Proposed transmitter power ____ watts, ______dBm.	sec. 4.4.44
(39) Path length ______ km.	worksheet 4.4-1
(40) Free space basic transmission loss, L_{bf}, ______dB.	fig. 4.2-7 or (4.2-1)
(41) Atmospheric absorption, A_a, ______dB.	fig. 4.2-8 and sec. 4.2.22
(42) Net loss, (37) + (40) + (41), ______dB.	
(43) Net gain (21) + (22) + (38) (dBm) ______dBm.	
(44) Expected median receiver input power, P_r, (43) - (42) ____dBm.	
(45) Order of diversity used______.	
(46) Type of diversity combiner used______.	
(47) Rain rate zone ______.	fig. 4.2-11 or 4.2-13

Worksheet 4.4-5. Link Design Summary, Part 2

4.4.4 Calculating tower heights

4.4.4.1 The minimum antenna height above ground should generally be at least 4 meters to maintain clearance of security fences, vehicles, personnel, etc. If sites with suitable elevations are not available, or if the path is partially obstructed, necessary path clearance is obtained by increasing the height of the antenna towers at either one or both sites.

4.4.4.2 In determining optimum antenna heights and thus implicitly tower height, several factors are important for systematic analysis:

a. Terrain clearance required for the particular path.
b. Effect on atmospheric penetration angle.
c. Cost.
d. Antenna height requirement for adjacent paths with antennas located on the same tower.
e. Limitations because of local ordinances.
f. Logistics.

4.4.4.3 A systematic analysis considering factors (a.), (c.), (e.) and (f.) which comes from [2], pp. 3 - 64, appears in table 4.4-1. This method may be adequate for fairly smooth terrain.

4.4.4.4 Using a value of the effective earth's radius factor k based on the worst subrefractive index gradient estimated, or on k = 2/3, whichever is less, draw a ray path overlay (Section 4.2.15) for the path between terminals; also on the overlay draw the 0.6 Fresnel zone clearance from the information in Section 4.2.18. Similar overlays should be drawn for adjacent paths. On the basis of the six considerations, manipulate the overlays with respect to the profiles to determine the desired antenna heights.

4.4.4.5 The tower height required for clearance over smooth earth increases as the square of the path length. Figure 4.4-2 shows the relationship for tower height versus path length for k = 2/3. As can

No.	Action	Comment	Result
1	Plot path profile of hop on linear graph paper.	Use maps with 1 : 25,000 scale and up to 5-meter contour intervals, if available; otherwise, use best available maps and other reliable information sources (Field surveys, etc.).	
2	Plot the radio ray path between the terminals, using the procedure given in sect. 4.2.15 using k = 2/3.	Start from ground elevation even though path goes "underground". This will be corrected later.	
3	Calculate the radius of the first Fresnel zone, R_1, at 1/4, 1/2, and 3/4 of the total distance, d, between terminals, using the equation: $0.6R_1 = 0.6\left(\lambda\frac{d_1 d_2}{d}\right)^{\frac{1}{2}}$. See sect. 4.2.17 and 4.2.18.	λ is the wavelength in meters; d_1 and d_2 are defined by the equation: $d_1 + d_2 = d + \lambda/2$. They represent distances to points on an ellipsoid of revolution surrounding the direct path.*	R_1, in meters
4	Plot appropriate points for 0.6 R_1 beneath the radio ray path; plot a smooth curve outlining the lower edge of 0.6 of the first Fresnel zone, by connecting these points.	Repeat step 3 to obtain values for 0.6 R_1 at other distances, if required for accuracy.	
5	Adjust height of lower edge of zone until it clears all obstacles, by raising height of antenna at each end the required amount.	It is not necessary to raise both ends the same amount. The objective is to raise each one the least amount possible, which will result in unequal amounts if the obstacles are not midpath.	
6	If the height above ground at either end does not exceed the height that can be provided by towers available for the hop, use this height above ground as the antenna elevation in the path attenuation calculations to follow. If the height above ground does exceed the height of available towers, use the maximum tower height in the attenuation calculations.	Tower heights may be limited by terrain, logistics, local rules, mobility requirements, cost, etc.	Antenna elevations

*Note d, d_1, d_2, R_1, and λ must be in the same units.

Table 4.4-1 Determination of Antenna Elevations

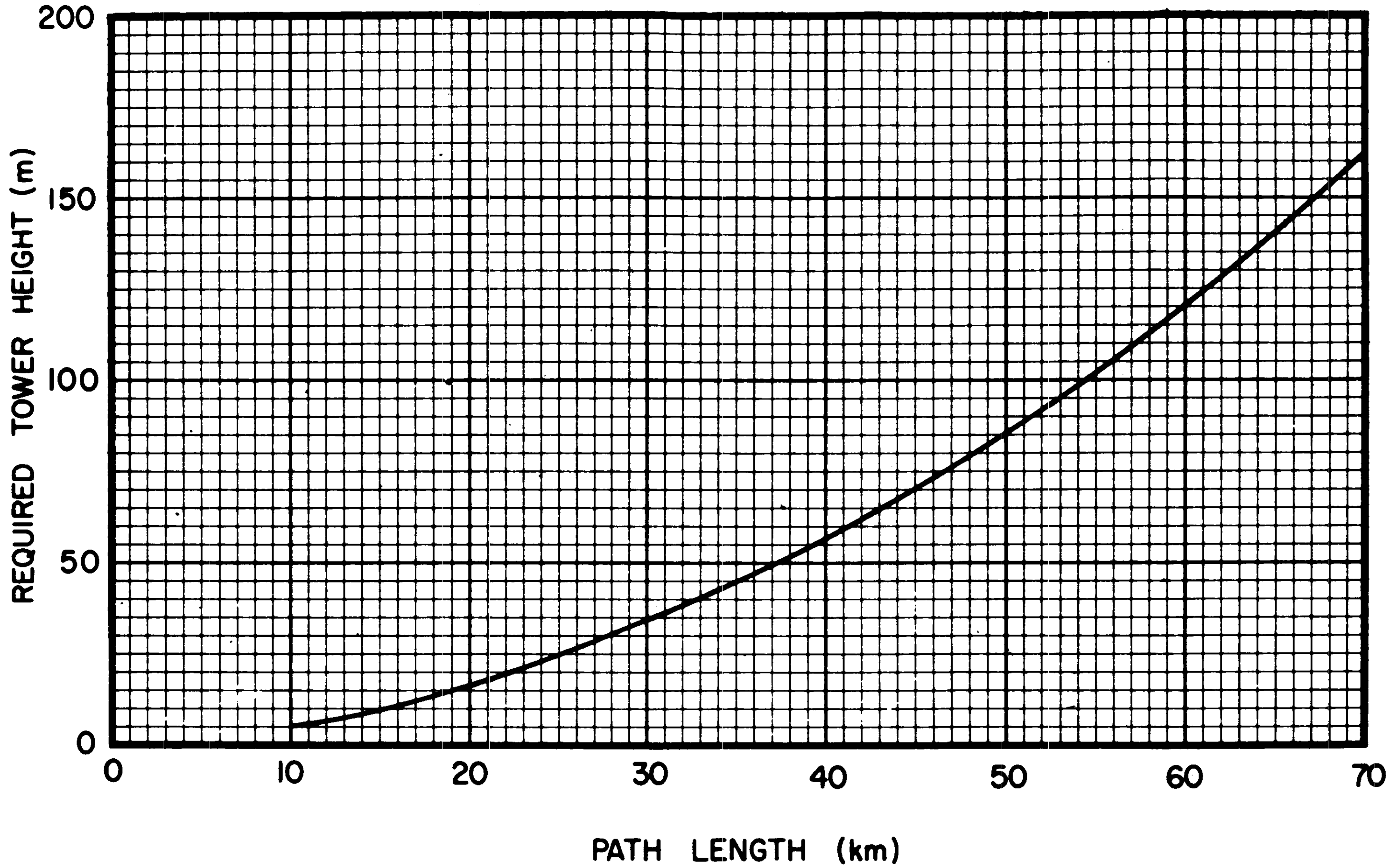


Figure 4.4-2 Tower Height Required for Smooth Earth Clearance for k = 2/3, 0.6 First Fresnel Zone Clearance and Equal Antenna Heights

be seen from figure 4.4-2, an 85 m tower height is required for a 50 km path while only a 56 m height is required for a 40 km path.

4.4.5 Line-of-sight propagation over smooth earth and irregular terrain

4.4.5.1 For a linear, isotropic, homogeneous medium, propagation is in a straight line; the amplitude is subject to the inverse distance law, and the phase varies linearly with distance. This "free-space" propagation is a convenient reference for the design of line-of-sight radio links since the median atmosphere and the terrain usually can be approximated as a piece-wise homogeneous medium by application of the effective-earth-radius concept. In this sense, with proper system design (site selection, etc.), the reference condition is commonly achieved for median atmospheric conditions, and the observed signal variations are not serious during most of the time. Serious variations such as deep fading generally occur in certain geographical locations and at particular times of the day and year; i. e., under certain meteorological conditions (marked departures from the median refractivity structure) and terrain geometries. Such conditions are sufficiently understood in most cases to be categorized in terms of why, where, and when, but their predictability is not suitable for inclusion in formal, probabilistic, telecommunication-system-design procedures. However, these conditions can be described so that the systems engineer, in the course of his site survey, could recognize those paths for which fading is likely to occur. As design constraints permit, he can then either avoid the cause of fading or incorporate appropriate remedies.

4.4.5.2 The most basic definitions of fading are in terms of the propagation mechanisms involved: refraction, reflection, diffraction, scattering, focusing, absorption, etc., as well as the guiding of radio waves. These are basic because they determine the statistical behavior with time of the measurable field parameters (amplitude, phase, and polarization) and the frequency or spatial selectivity of the fading. The purpose here is to describe the manner in which atmos - phere and terrain support these mechanisms in terms of simple ray theory referencing the appropriate sources for further detailed quantitative evaluation. Although simple ray theory is ideal for visualizing atmospheric and terrain effects, a full description requires wave theory, asymptotic propagation theory or extensions of ray theory.

4.4.5.3. It has already been shown in Section 4.2.21 that the transmission loss is free space for line-of-sight links can be expressed as

$$L = L_{bf} - G_t - G_r \quad dB \tag{4.4-1}$$

where all terms are in dB. L_{bf} is the free-space basic transmission loss from (4.2-20), and G_t and G_r are the expected antenna power gain (relative to an isotropic radiator) for the systems design conditions. An additional attenuation A, attributable to atmospheric and terrain effects, must be con sidered in system design, particularly in fading situations, when it becomes excessive. For long-term value, a term A_a dB is added to L which represents the average atmospheric absorption as discusses in Section 4.2.22.

4. 4.6 Refractive index gradients

4.4. 6.1 This section briefly describes some of the available information about the refractive index structure near the earth's surface that is significant in connection with microwave fading mechanisms. Much of the material in sections 4. 4.6 through 4.4.20 was taken from [35].

4.4. 6.2 The average bending of an electromagnetic wave propagated through the troposphere may usually be represented by ray theory in terms of a radius of ray curvature related to the average gradient of refractive index. If we assume that the refractive index n of the air varies linearly with the height h for the first few tenths of kilometer above the earth's surface and does not vary in a horizontal direction, then the radius of curvature r of the radio ray relative to the radius of the earth, $r_0 \approx 6370$ km, may be expressed in terms of the gradient, $\Delta n/\Delta h$, by:

$$r/r_0 = k \approx [1 + r_0 \frac{\Delta n}{\Delta h}]^{-1}. \quad (4.4\text{-}2)$$

The parameter k is usually called the effective earth-radius factor. The gradient is usually expressed in terms of the refractivity, $N = (n - 1) 10^6$, so that

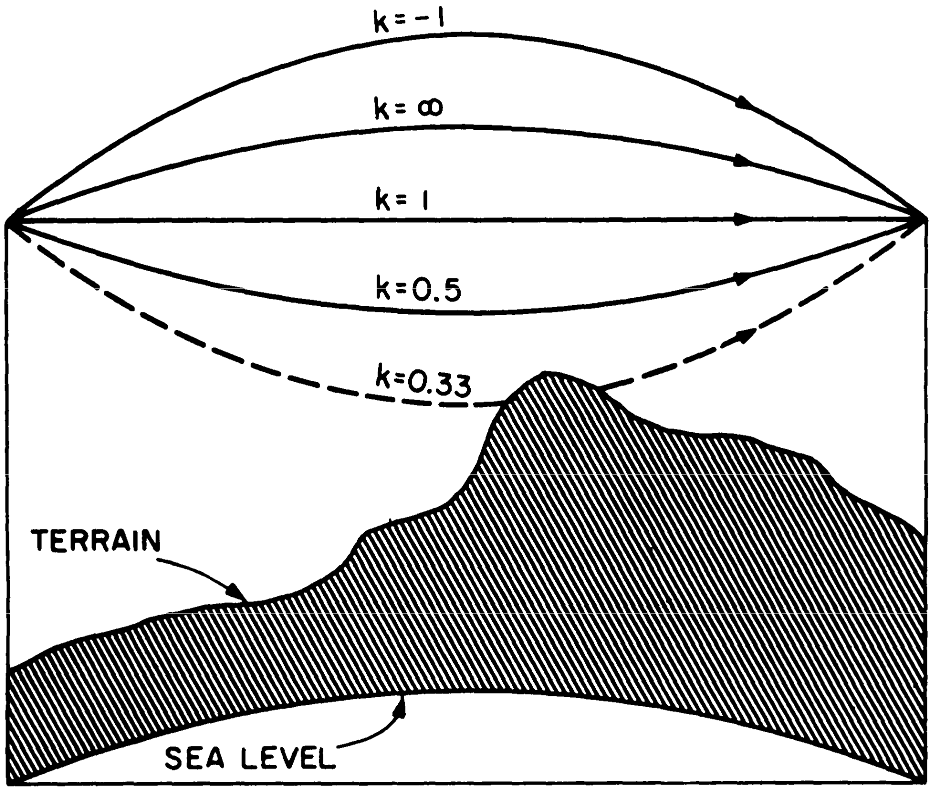
$$\frac{\Delta n}{\Delta h} = \frac{\Delta N}{\Delta h} \; 10^{-6} \text{ N units/km}, \quad (4.4\text{-}3)$$

and

$$k \approx [1 + (\frac{\Delta N}{\Delta h}) / 157]^{-1}, \quad (4.4\text{-}4)$$

where h is in km. Several values of k and AN/Ah are listed in figure 4.4-3, where the corresponding ray paths are illustrated. The vertical scale of figure 4.4-3 is exaggerated, relative to the horizontal scale, to make the differences in curvature noticeable.

4.4.6.3 For 0 < k < 1.0, encountered for positive gradients (subrefractive conditions), the ray joining two terminals passes close to the earth. The ray may even be interrupted by the surface (k = 0.33 in fig. 4.4-3) so that the receiving terminal is beyond radio line of sight. For the commonly encountered situations $-157 \leq \Delta N/\Delta h \leq 0$ where $\infty \geq k \geq 1.0$, the rays are farther removed from the earth's surface. At the critical value $\Delta N/\Delta h = -157$ N units/km, $|k| = \infty$;and the curvature of the ray path is equal to the curvature of the earth; thus the ray paths are parallel to the earth's surface. Conditions for $\Delta N/\Delta h < -157$ are termed super critical; the corresponding values of k from (4.4-4) are negative, and trapping of the radio rays is possible. Consequently, values of $\Delta N/\Delta h < -157$ are commonly referred to as a trapping or ducting



*ΔN/Δh	k
314	0.33
157	0.5
0	1.0
-157	∞
-314	-1.0

*N UNITS/km

Figure 4.4-3 The Bending of Radio Rays for Linear Refractivity gradients

gradients. The relation between k and $\Delta N/\Delta h$, discussed above and discussed above and given by (4.4-4) is plotted in figure 4.4-4.

4.4.6.4 To illustrate that the range of conditions shown in figure 4.4-4 is realistic, a distribution of average gradients for Cape Kennedy, Florida, is presented in figure 4.4-5. The distribution was determined from February, May, August, and November data selected from a 7-year period. Preliminary y investigations for other locations throughout the world indicate that figure 4.4-5 at least exemplifies maritime or coastal locations with relatively smooth terrain. Much of the available information is included in a recent World Atlas of refractive index gradients [39].

4.4.6.5 Note that the median refractive index gradient from figure 4.4-5 is approximately -60 N units/ km which differs from the commonly used median value of approximately -40 N units/km corresponding to k = 4/3. Even more important is the range of gradients which must be considered when plotting terrain profiles. A profile plotted for k = 4/3 or a value corresponding to the median gradient can be very misleading -- it corresponds to a situation that is not particularly significant for fading situations and can obscure the dynamic nature of microwave propagation through the lower atmosphere. Preferable procedures are available. For example, charts are commercially available for plotting the various ray paths between two terminals (such as in fig. 4.4-3) for a range of k values. This is applicable to any profile but avoids much computation when the profile is a simple rectangular height-versus-distance profile taken directly from a map.

4.4.6.6 Strong refractive index gradients occur over a limited range of elevation (layers) at, or above, the terrain surface.

4.4.6.7 Figure 4.4-6 illustrates those super refractive surface gradiients caused by the radiation of heat from the surface to a clear sky.

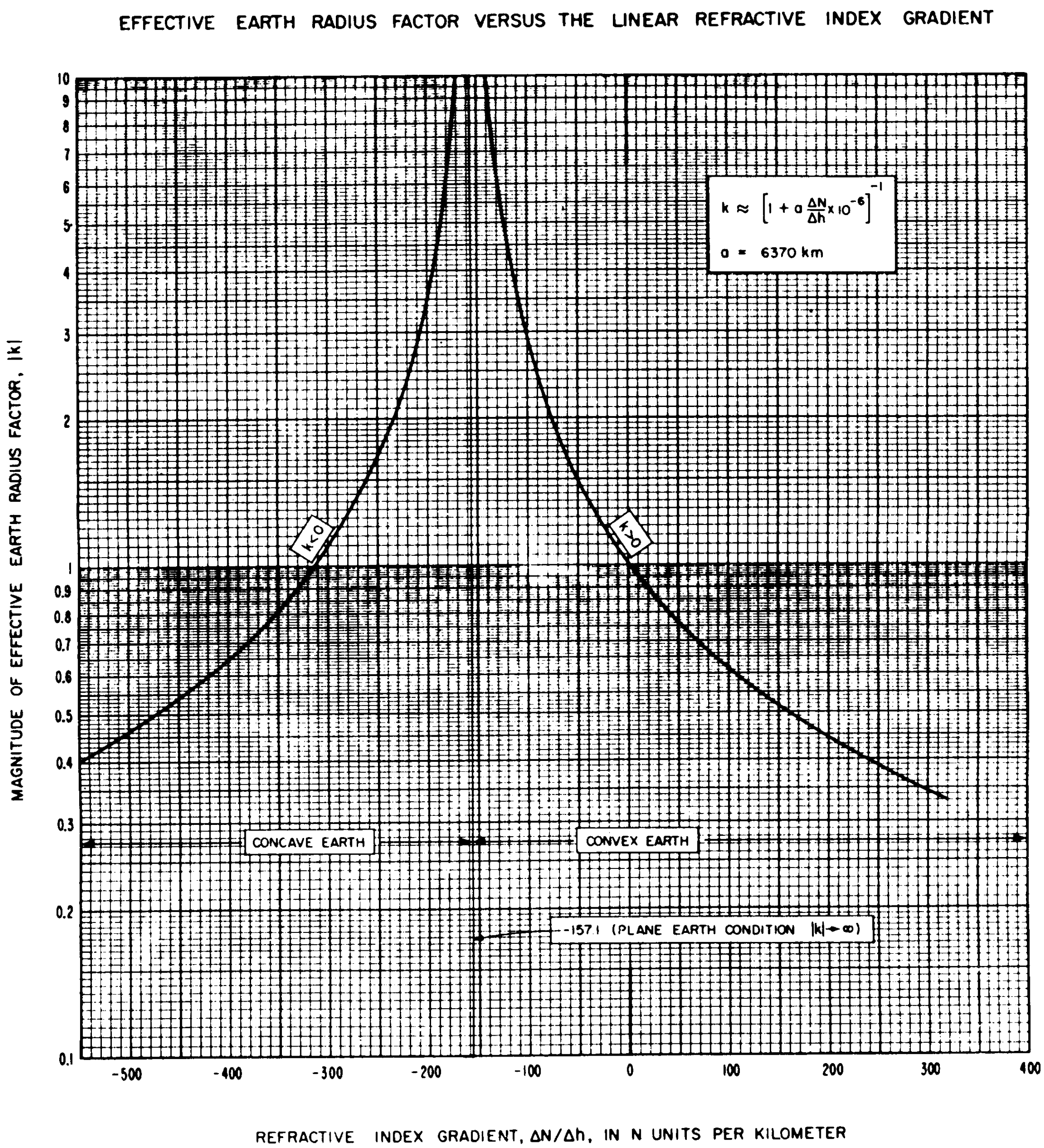


Figure 4.4-4 Effective Earth Radius Factor versus the Linear Refractive Gradient

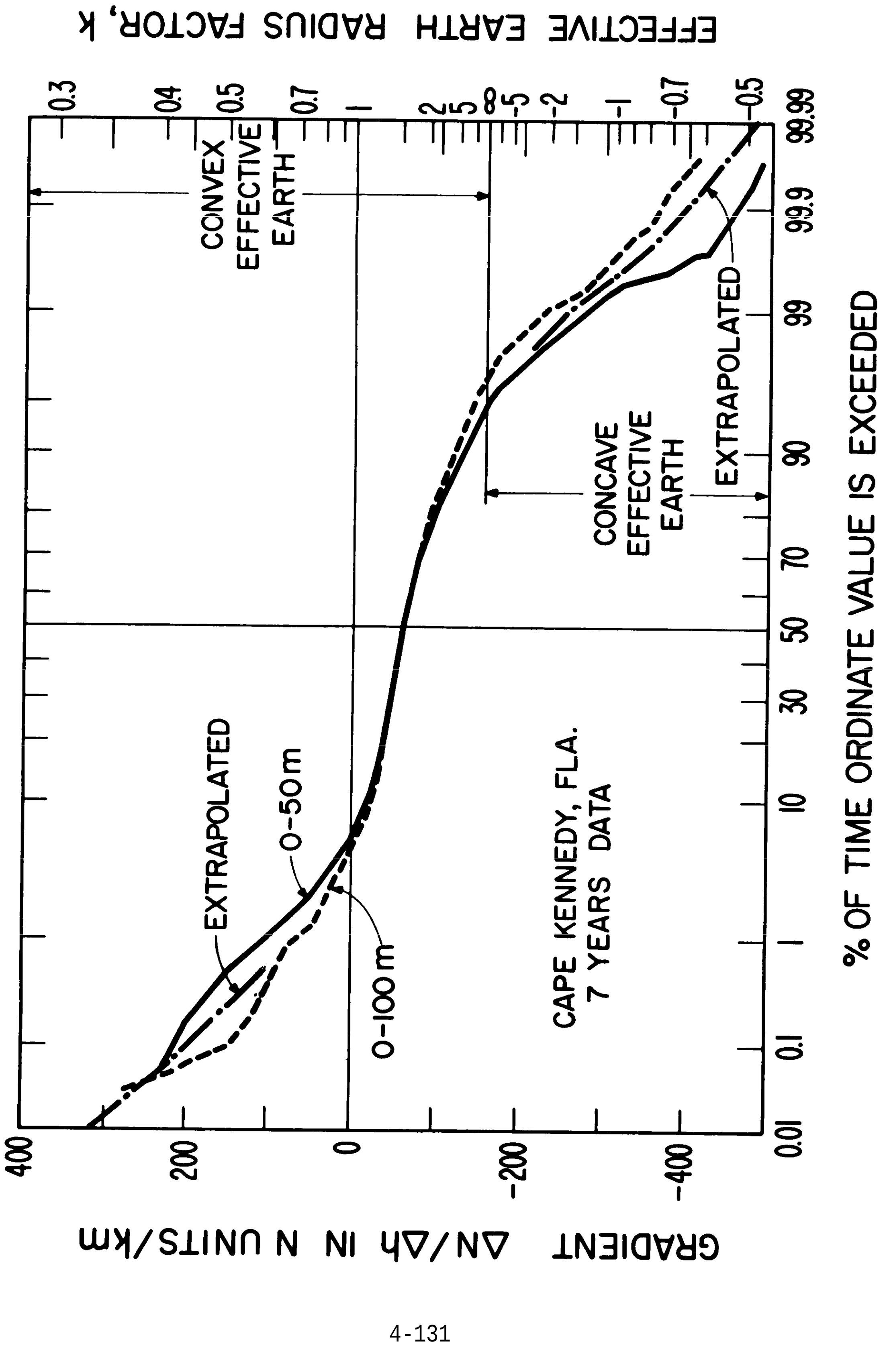
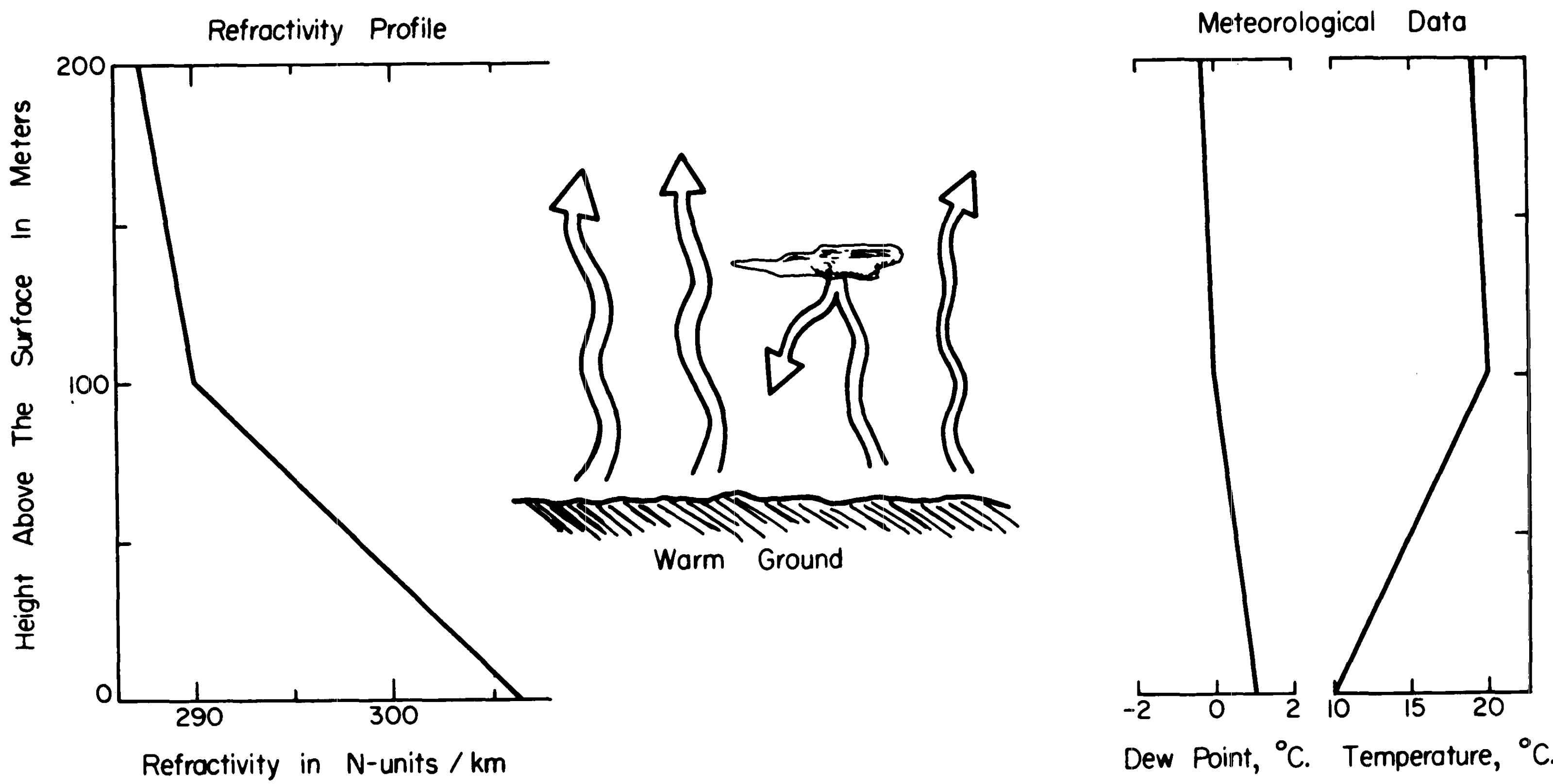


Figure 4.4-5 A Distribution of Refractive Index Gradients Averaged over the First 50 and 100 Meters Above the Surface



OCCURRENCE: Clear skies and light surface winds at night permit a considerable cooling of the earth's surface due to the radiation of heat to space. The air near the surface also cools, resulting in a temperature inversion.

Figure 4.4-6 Surface Superrefractive Layer Due to Radiation

At night, clear skies and light surface winds permit considerable cooling of the earth's surface. This can cause the formation of a temperature inversion (an increase of temperature with height) and produce a strong super refractive gradient near the surface -- a condition that can cause substantial fading on microwave links.

4.4.6.8 Extreme subrefractive or superrefractive gradients are less likely to occur above rough terrain. Line-of-sight propagation paths between high points of mountainous terrain will, in general, have more linear distributions of gradients with reduced standard deviations (compared to that depicted in figure 4.4-5). Thus the amount of fading and variations in signal level may be greatly reduced. There are exceptions to this, such as in the coastal range of mountains of northern Chile, where larger gradients are attributable to the intrusion of the trade wind inversion among the mountain peaks. Also the median refractive index gradients for oversea paths are less (more negative), A detailed, informative treatment of the refraction of radio waves and the refractive index structure of the lower atmosphere may be found in [38].

4.4.7 Determination of the range of refractivity gradients

4.4.7.1 If adequate information on the space and time variations of refractivity gradients were always available, rather exact microwave design procedures could be developed. At the present time, however, knowledge of refractivity variations is somewhat limited. The available statistical data are based largely upon studies of radiosonde observations (RAOBs) taken routinely by weather services in most parts of the world. These observations are generally made no more than twice each day, and at widely separated points (distances of 250 to 400 km between stations are common in the U.S.), and they do not provide sufficient detail on thin atmospheric layers which can have a significant effect on radio propagation. Nevertheless, statistics accumulated from the RAOB data can be used to advantage in the design of line-of-sight links, particularly when there is no record Of operational experience in an area in which a new microwave system is being considered.

4.4.7.2 Statistics of refractivity obtained from climatological RAOB data have been used to prepare the "World Atlas of Atmospheric Radio Refractivity" [39]. This presents a variety of information in the form of maps, graphs, and tables, including the following:

a. World maps of monthly mean ΔN (the difference in refractivity between the surface and 1 km),

b. Mean surface refractivity (N_s) for each month for more than 250 stations in all parts of the world.

c. World maps of the surface-based 100 m layer gradient probability, (based upon an analysis of about 100 stations), 4 months of the year.

d. Cumulative probability distribution graphs of surface-based 100 m gradients for 22 stations 4 months of the year.

Thus this atlas provides a convenient source of information upon which to base estimates of extreme refractivity gradients (super refractive and subrefractive) in all parts of the world. However, it does not provide as much detail as is desirable for link design, except for a relatively few locations, and should therefore be supplemented with other data whenever possible. Additional refractivity data for certain areas may be available from the Air Force Environmental Technical Applications Center, Washington, D.C. or from communications laboratories in various countries.

4.4.7.3 It may sometimes be desirable to obtain RAOB data from a nearby station and calculate the observed refractivity gradients (for example, during a period of path testing). The following equation is used [73]:

$$N = \frac{77.6}{T}\left[P + \frac{4810\, e_s\, RH}{T}\right] \qquad (4.4\text{-}5)$$

where

N = refractivity in N units

P = pressure in millibars

T = temperature in degrees Kelvin

e_s = saturation vapor pressure in millibars*

RH = relative humidity in percent.

Since the gradients are usually given in terms of "N units/ km"; the height interval of the observation must be noted. Thus, if the refractivity at the surface is 350 N units and at 100 m the value is 330, the gradient over the 100 m interval is -200 N units/km. A very convenient nomogram [64] is available for determining refractivity directly from parameters used in RAOB reports (pressure, temperature, dewpoint), and is reproduced here in figure 4.4-7. When carefully used, this provides sufficient accuracy for most engineering investigations.

4.4.7.4 A graphical means of obtaining the effective earth's radius factor k from refractivity gradient data was shown in figure 4.4-4.

4.4.7.5 The limitations of RAOB-derived refractivity estimates should be kept in mind when applying these data to design problems. A RAOB station near the coast is likely to experience very different low-level gradients than a location even a few miles inland. Differences in elevation, terrain roughness, vegetation, and exposure to prevailing winds may result in significant local variations in gradients. There also are indications that the extreme gradients sometimes indicated by the point radiosonde observations reflect conditions that exist over a

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* See Smithsonian Meteorological Tables.

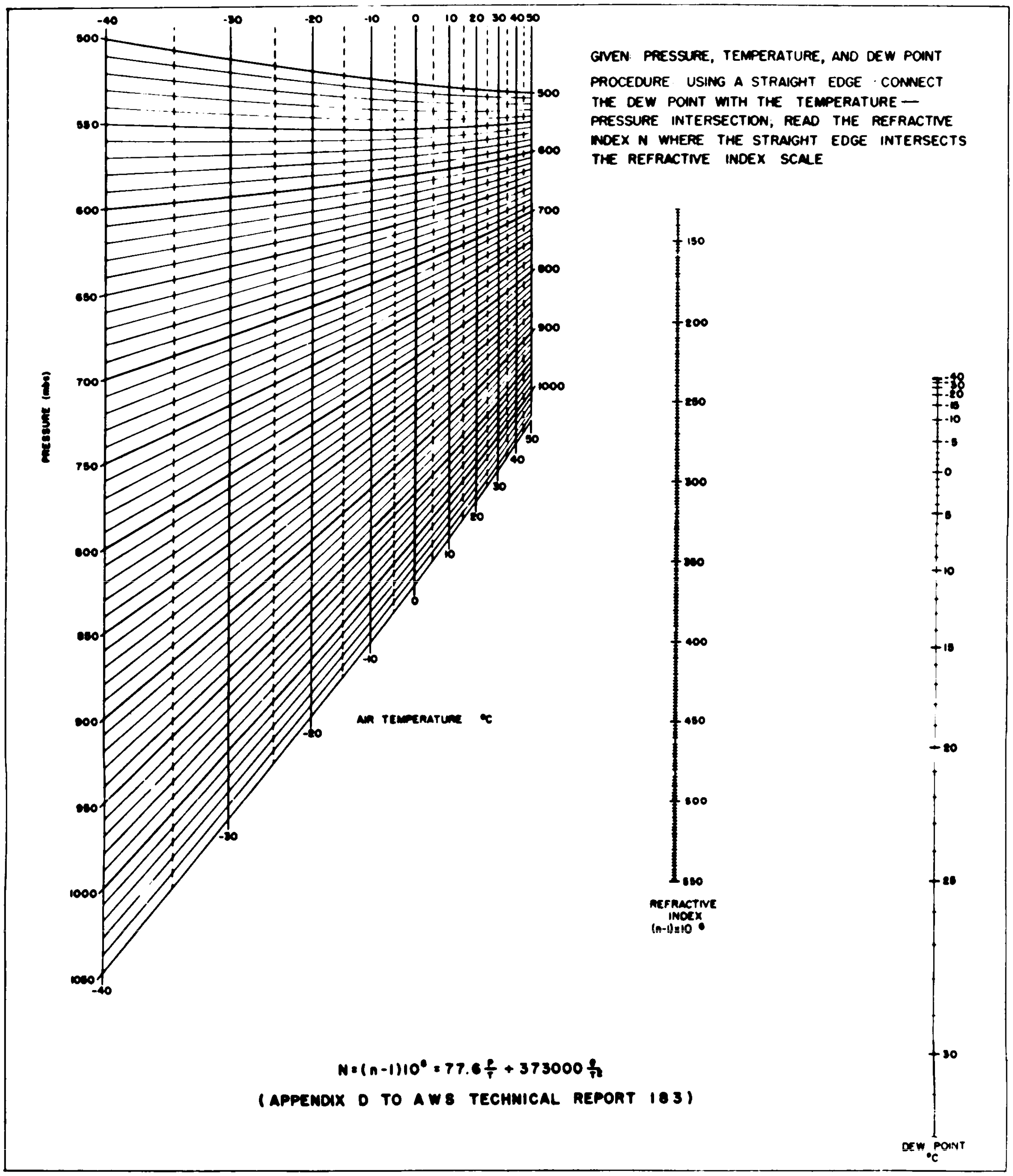


Figure 4.4-7 Refractive Index Nomogram.

very small area, and that the average conditions over an entire radio path in the same vicinity would be considerably less severe.

4.4.8 Fading mechanisms

4.4.8.1 The significance of the refractive index structure for microwave fading is best illustrated by the variety of situations that produce such fading. Here we classify and illustrate these fading mechanisms and identify the supporting refractive index STRUCTURES. A general discussion of the fading signal characteristics and their remedies is provided.

4.4.8.2 Fading at microwave frequencies for line-of-sight paths through the troposphere may be categorized as multipath fading and power fading. Each category includes several fading mechanisms with characteristics that often permit their identification.

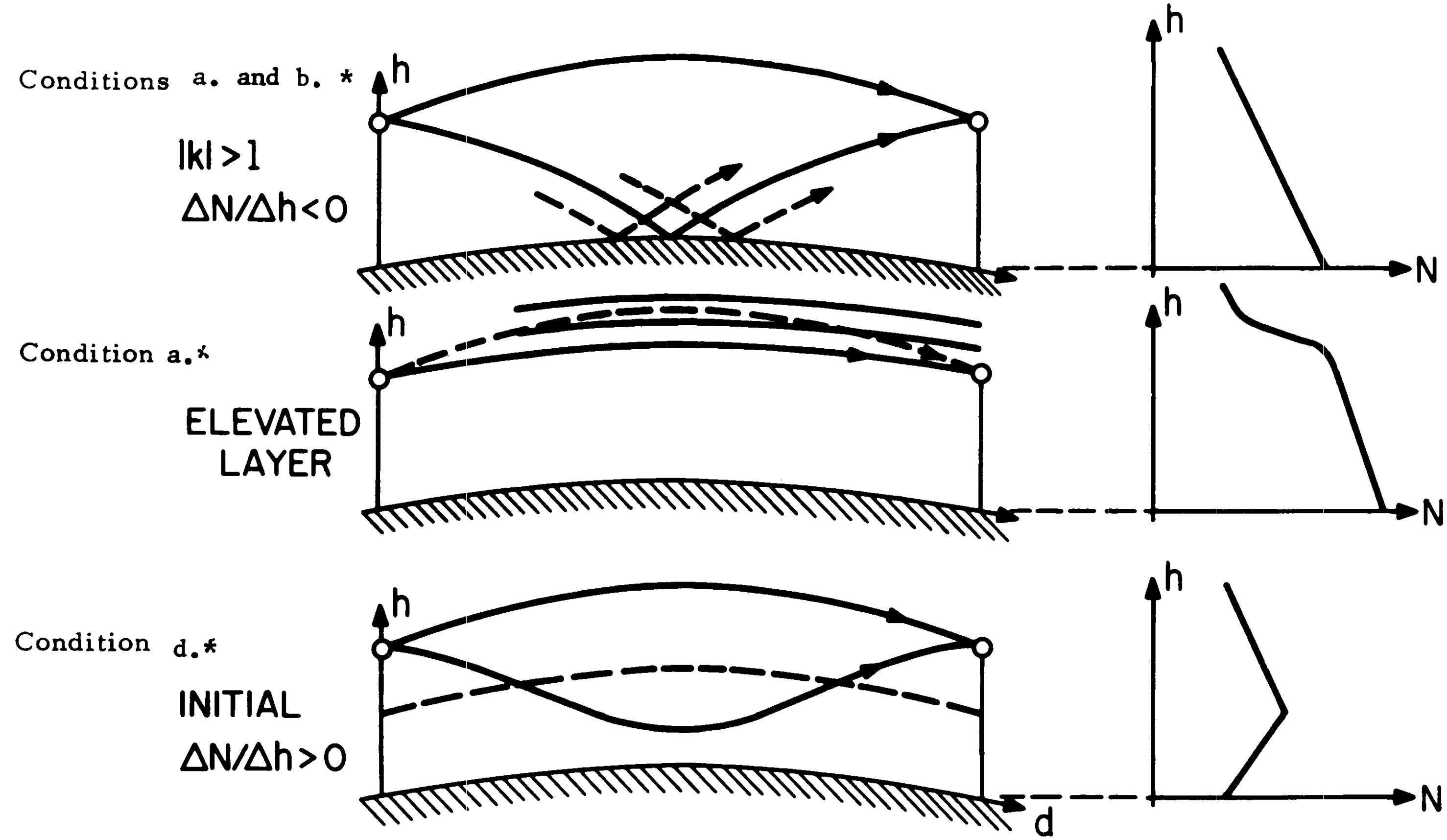
4.4.9 Multipath fading

4.4.9.1 As the refractive index gradient varies, multipath fading results from interference between the direct wave and

a. the specular component of the ground-reflected wave;
b. nonsecular components of the ground-reflected wave;
c. partial reflections from atmospheric sheets or elevated layers; or
d. additional direct (nonreflected) wave paths.

These additional direct wave paths in (d.) can occur due to either the surface layers of strong positive refractive index gradients or the horizontally distributed changes in refractive index -- as may be encountered with a weather front. These multipath fading mechanisms are illustrated in figure 4.4-8.

4.4.9.2 The depths of fades encountered for these multipath phenomena can be quite severe, depending upon the effective reflection



* See text; paragraph 4.4.9.1

Figure 4.4-8 Multipath Fading Mechanisms coefficients or the relative amplitudes of the component waves. Mechanisms (a) and(c) can produce fades persisting for minutes. During such fades the nonsecular-ground-reflected components (normally small for small grazing angles) can cause additional interference (with the direct plus specular component), providing even deeper, more rapid fades having durations of the order of seconds. An illustration of multipath fading (direct plus ground-reflected wave) is presented in figure 4.4-9 to show the characteristic return of signal level to, or above, the free-space value. In figure 4.4-9, a basic transmission loss [8] of approximately 139 dB corresponds to that for the free-space signal level. Multipath fading tends to be less frequent during the day, particularly during the afternoon hours, when conditions more closely approach a median or reference atmospheric structure with constant gradients.

4.4.9.3 Figure 4.4-10 is an illustration of the frequency selectivity of multipath fading and shows recordings of received signals of two transmission frequencies over a common propagation path. On an instantaneous basis the two recordings appear uncorrelated. Note, however, that with an allowance for time lag the two signals appear to be highly correlated. This time lag for high correlation, which is a measure of the effective (frequency) diversity separations is a function not only of the frequency separation, but also of the refractive index gradient and its time rate of change. Thus the frequency spacing of figure 4.4-10 is inadequate if fades of 20 dB below the 139 dB free-space level are unacceptable.

4.4.9.4 The multipath fading due to the interference from specular ground reflections can be avoided by eliminating one of the field components. The specularly reflected wave can be severely reduced by special “anti-reflective wave” antenna arrays [37], [58] or by the use of Fresnel zone screens [46], [69], and [74]. These devices assume

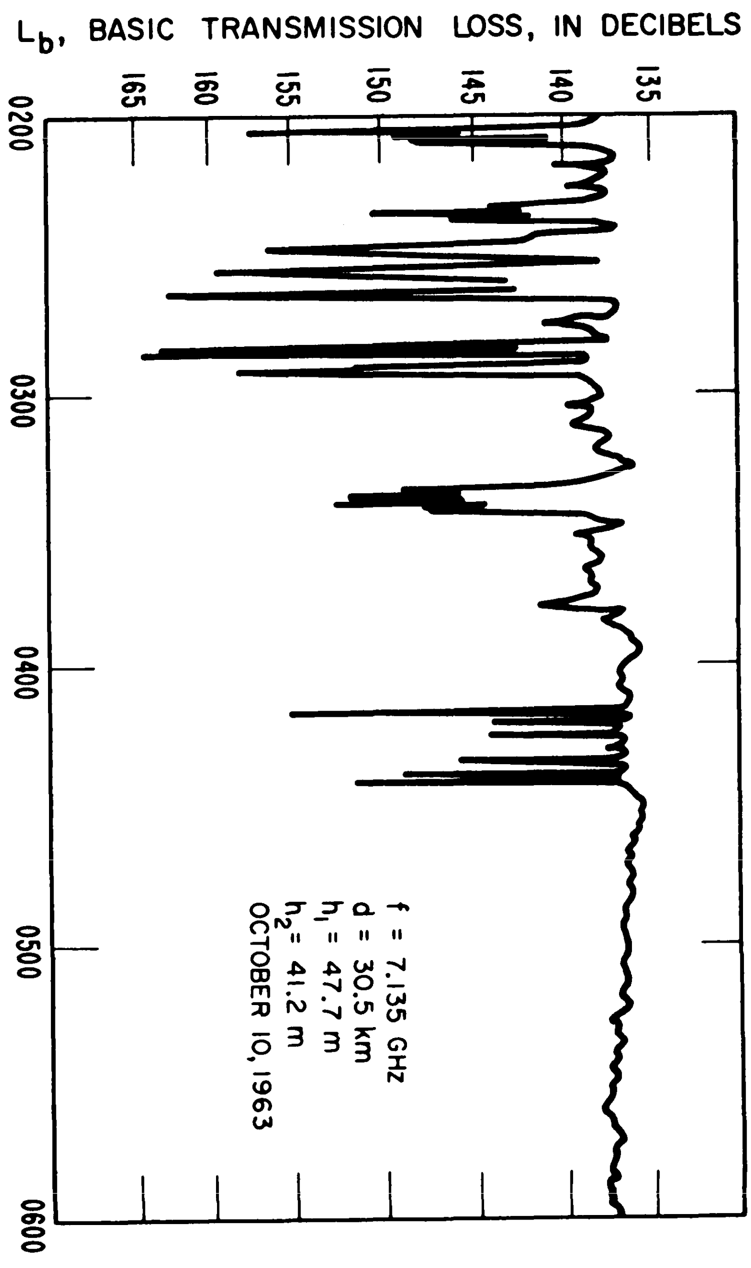


Figure 4.4-9 Example of Multipath Fading

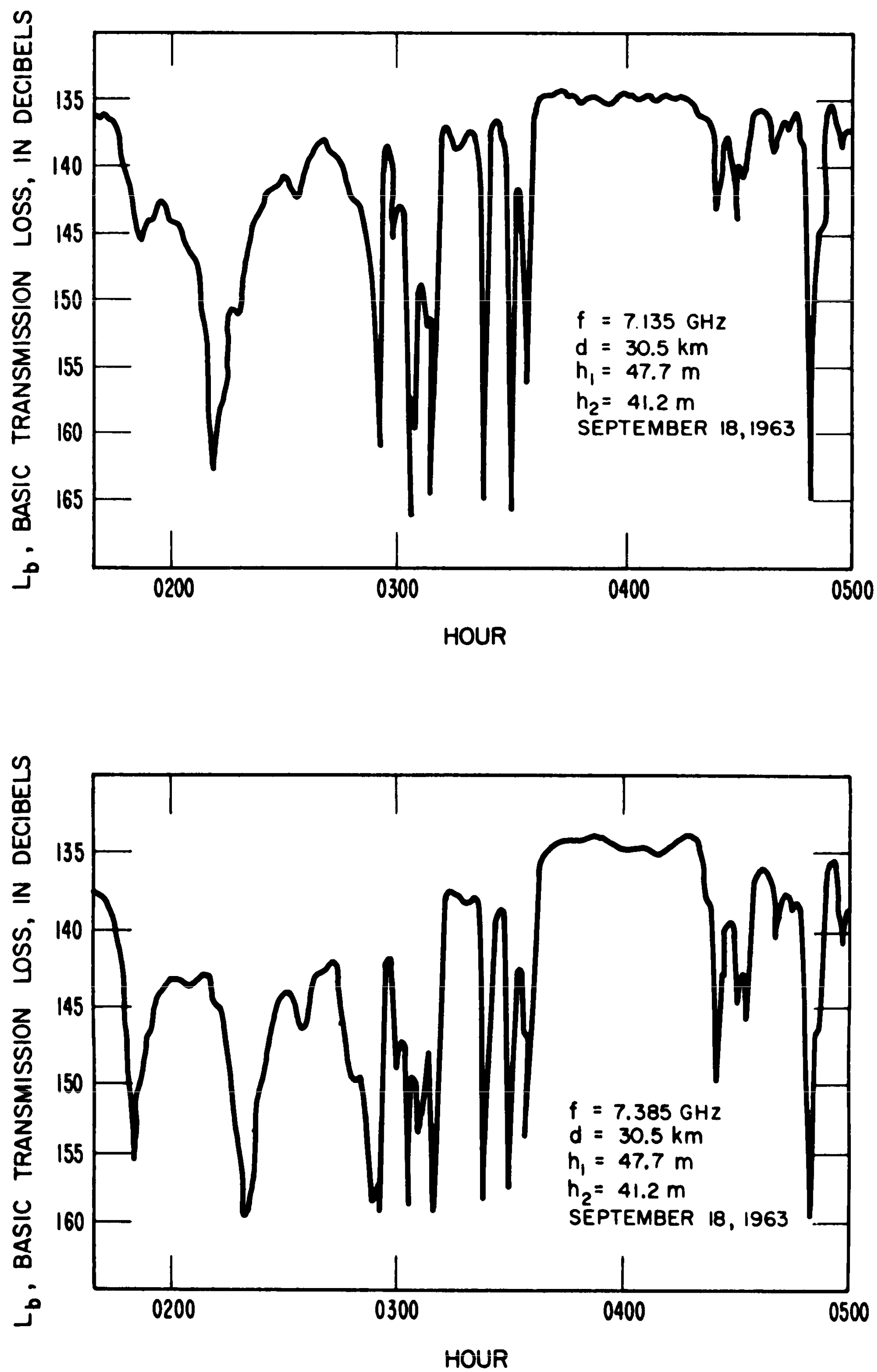


Figure 4.4-10 Example of Frequency Selectivity for Multipath Fading

that the range of refractive index gradients will not be too great. For propagation over rough irregular terrain, this last condition is usually met, and the effects of ground reflections may then be avoided by the proper choice of antenna sites or antenna designs. To date, however, the most effective counter measure for general multipath fading over wide ranges of refractive index gradients is diversity reception [36], [47], [59], and [60].

4.4.10 Multipath characteristics

4.4.10.1 Multipath fading caused by reflection from the sea or land surfaces or from layering in the atmosphere produces amplitude variations of the received signal level characterized by: (1) the maximum signal between fades exceeding, to some extent, the free-space level, (2) frequency and duration of fades related not only to the path geometry and transmission frequency but also to the variation of the refractive index structure with time, and (3) usually one of a specific family of signal level distributions. A quantitative description of these characteristics will provide a means of identifying the probable causes of fading when it is observed.

4.4.10.2 The peak values of multipath signal levels depend upon the number of signal components and their relative amplitudes and simply correspond to the sum of all component voltages. Similarly, the number, relative amplitude, and relative phases of the components determine the cumulative distribution of the levels corresponding to their vector sum. The first requirement, therefore, is a description of the relative amplitudes and phases of the component voltages. This is not practical, at present, for all the situations of interest. Although there have been significant advances in the theoretical treatment of reflection or scattering from atmospheric layers in terms of specific refractive index profiles [43], [52], and [76], and experimental investigations have been reported, the state-of-the-art has not yet provided engineering expressions for the magnitude and phase of the multipath components that produce severe fades at microwave frequencies and are attributable to reflection from atmospheric layers. We can, however, identify the distributions of signal amplitudes that would be expected; they coincide with those encountered for multipath produced by reflection and scattering from irregular terrain, and signal characteristics will be quite similar to those shown in figures 4.4-9 and 4.4-10.

4.4.11 Power fading

4.4.11.1 Power fading results from the partial isolation of the transmitting and receiving antennas because of:

a. intrusion of the earth's surface or atmospheric layers into the propagation path (earth-bulge fading or diffraction fading*);

b. antenna decoupling due to variation of the refractive index gradient;

c. partial reflection from elevated layers interpositioned between the terminal antenna elevations;

d. "ducting" formations containing only one of the terminal antennas; and

e. precipitation along the propagation path.

---

* When a strong atmospheric layer intrudes into the direct propagation path between transmitter and receiver, the effect is much like that for intrusion of the earth's surface. For example, the energy represented by ray paths which strike the surface of a super refractive layer, at grazing angles of more than a few milliradians, penetrates the layer and is diverted from the direct path to the receiver location. The ray path at grazing incidence and those ray paths which pass above the layer provide a contribution to the receiver in the radio hole or "shadow" of the layer via the diffracted mode of propagation.

The received signal for these power fading mechanisms is characterized by a marked decrease in median signal level below that for free space and for extended periods of time. Some examples of these fading mechanisms are given in figure 4.4-11.

4.4.11.2 Power fading due to subrefractive index gradients is not likely to happen if adequate terrain clearance is provided, and does not commonly occur on well designed line-of-sight paths. Due to their low probability of occurrence and difficulty of analysis, quantitative prediction methods for such types of fading have not been developed, although their effect is significant because there is no diversity improvement and they often last much longer than multipath fades when they occur.

4.4.12 Power fading due to diffraction

4.4.12.1 The power fades that occur due to diffraction by the earth's surface are generally caused by a subrefractive (positive) gradient of refractive index as illustrated by the upper diagram of figure 4.4-11. This type of fading can persist for several hours and to depths of 20 or 30 dB below the free-space level. Such fading is essentially independent of small-scale changes in frequency, but may be reduced or avoided by proper choice of terminal antenna heights.

4.4.12.2 In mountainous terrain where terminals are located on dominating ridges or peaks, a clearance corresponding to a single Fresnel zone or less will usually be sufficient. The required clearance at mid path corresponding to n Fresnel zones in meters is

$$C_n \cong 8.66\sqrt{nd/f} \qquad (4.4\text{-}6)$$

from (4.2-17) subject to the same limitations as stated in paraqraph 4.2.18.4. Here the path length d is in kilometers and the transmission frequency f is gigahertz. If only a limited range of refractive Index gradients is encountered, a first Fresnel zone clearance, C_1, or less is sufficient. For those microwave paths where subrefractive

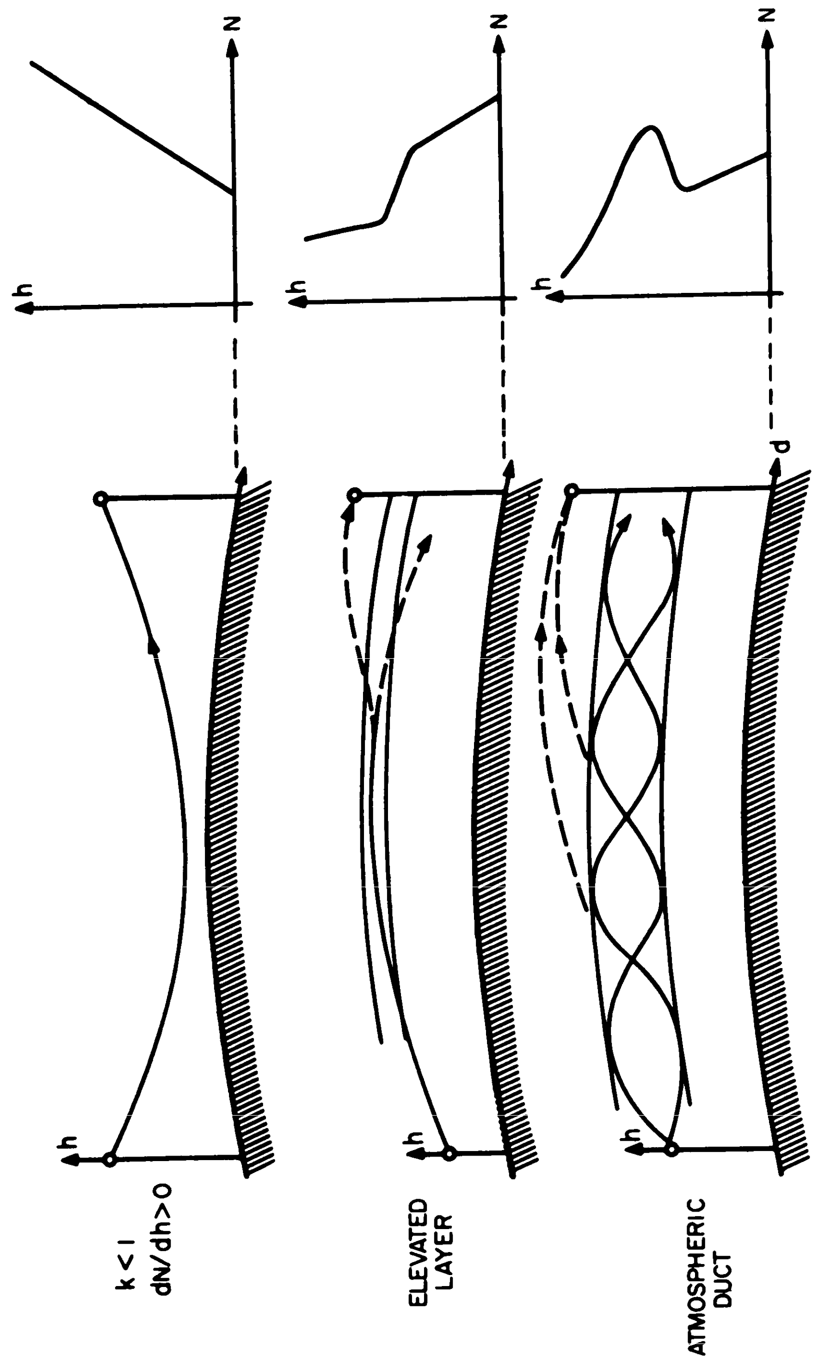


Figure 4.4-11 Attenuation Fading Mechanisms

index gradients are encountered, increased clearances are required. Consider a 2 GHz, 50 km propagation path with terminal antennas at equal heights. The smooth spherical earth diffraction loss for such a path is shown in figure 4.4-12 as a function of antenna height and path length when the refractive index gradient is 80 N units/km (corresponding to k $\simeq$ 2/3). Generally, the path length d in kilometers, the effective earth radius factor k (related to the gradient $\Delta N/\Delta h$ through 4.4-4, and the antenna heights, h_1, and h_2 in meters, for which the path would be just grazing (i.e., barely line-of-sight) are related by

$$d = \sqrt{12.74\ kh_1} + \sqrt{12.74\ kh_2}. \qquad (4.4\text{-}7)$$

This expression involves the familiar relation between antenna height and horizon distance over smooth earth, modified here for the metric system of units. For $h_1 = h_2 = 36.73$ m and k = 4/3, such a path would be just barely line-of-sight. A first Fresnel zone clearance, $C_1 = 43.3$ m from 4.4-6, would therefore require terminal antenna heights of approximately 80 m. Such a path would, however, still experience an attenuation of 10 dB for $\Delta N/\Delta h$ = 80 N units/km (see figure 4.4-12) and 23 dB for $\Delta N/\Delta h$ = 160 N units/km. To protect against a particular depth of diffraction fading, we must specify the required clearance in terms of the subrefractive gradients that may be encountered and the shape of the obstructing terrain.

4.4.12.3 Diffraction fading in the sense used earlier may also occur when a strong super refractive layer is positioned slightly below the terminal antennas. This was described in the footnote of paragraph 4.4.11.1 and is illustrated in figure 4.4-13. In such a situation the grazing condition is given by (4.4-7) when the h_1 and h_2 are the heights of the antennas above the top of the layer and k corresponds to the average gradient between each antenna and the top of the layer. This

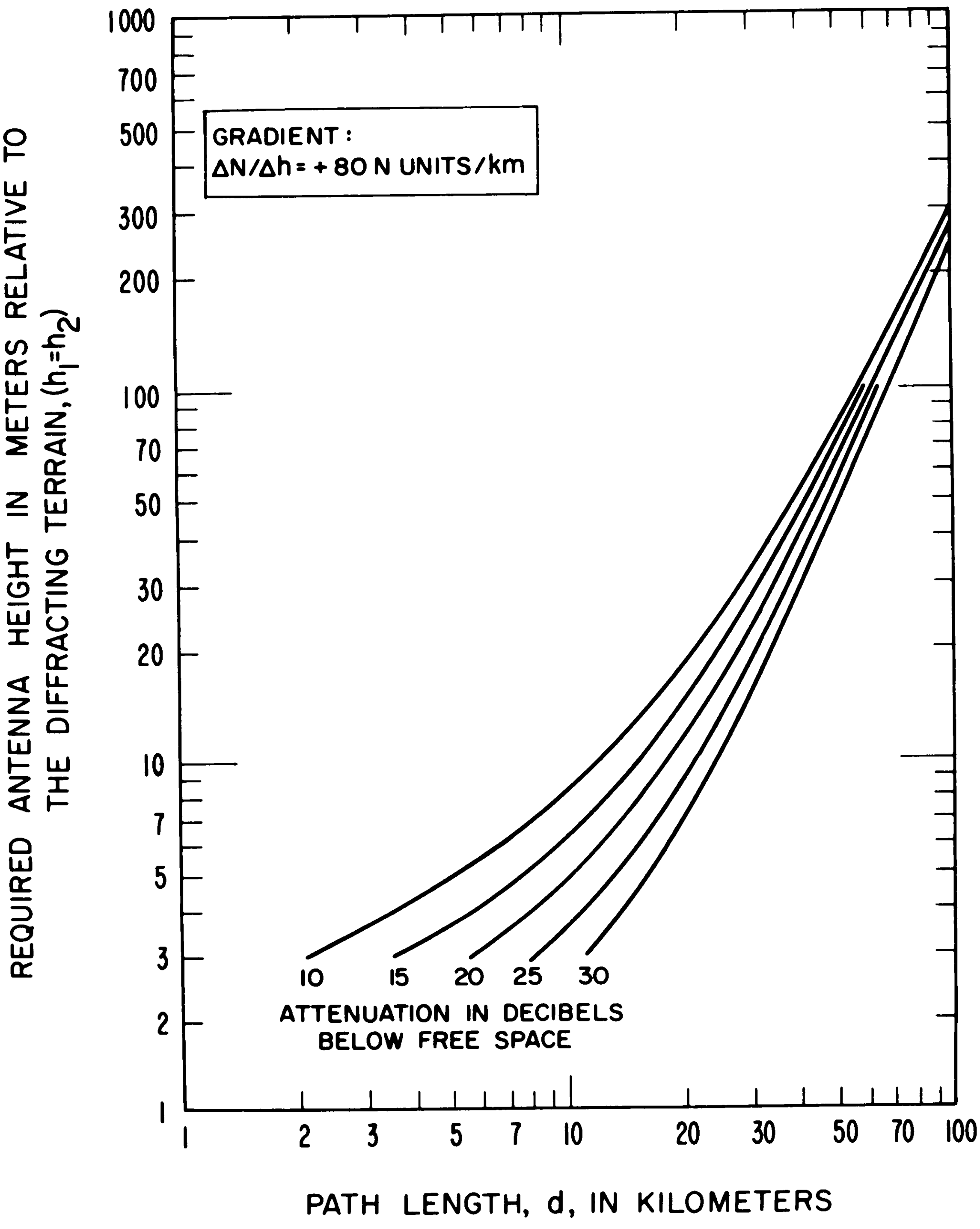


Figure 4.4-12 Attenuation Curves for a 2 GHz Propagation Path

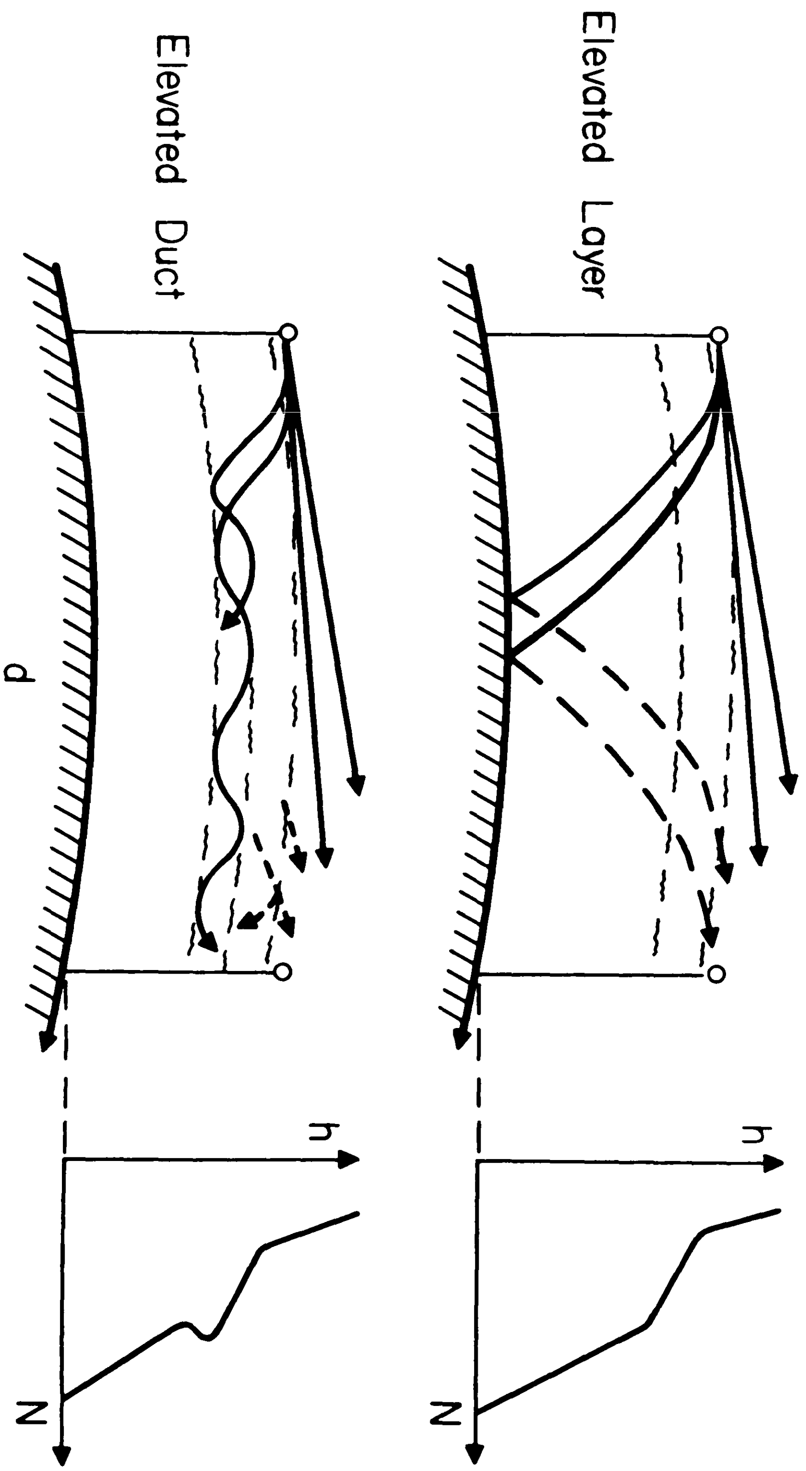


Figure 4.4-13 Diffraction Fading Due to Layering

situation is known as a radio hole in air-to-air applications [48], and [50]. The fading loss can be severe and may be estimated at grazing from calculating the parameters listed in figure 4.4-14, and using the curve given therein [49]. The severity of this type of fading will be reduced somewhat by terrain reflections or contributions from subrefractive layers positioned below the diffracting layer, which can direct energy back toward the receiver. These contributions, illustrated in figure 4.4-13, are a function of the gradients within and below the diffracting layer and also of the terrain roughness. They may, however, also produce multipath fading.

4.4.13 Power fading due to antenna "decoupling"

4.4.13.1 Power fading due to antenna "decoupling" refers to the loss of signal that occurs for transmission and reception of the signal outside of, or at the extremities of, the main lobe of the antenna pattern. For example, variations were observed in the vertical angle-of-arrival of up to 0.5° on a 38.6 km line-of-sight path [72]. This effect is proportional to the path length and can introduce several decibels of loss for high gain antennas and long line-of-sight paths. Such losses may be minimized by specifying a sufficiently broad antenna beam so that the expected variations of the angle-of-arrival are matched or exceeded. The variation is most conveniently expressed relative to the angle-of-arrival for flat earth ($k = \infty$) conditions. Thus, at the terminal whose antenna elevation is h_1 m, the angle-of-arrival from an antenna at an elevation of h_2 m and d_0 km distant, is given (for $k = \infty$) by*

$$\tan\theta_1 (k = \infty) = \left[(h_2 - h_1)/ d_0\right] 10^{-3}, \qquad (4.4\text{-}8)$$

or, for most practical situations where θ_1, is small,

$$\theta_1(\infty) \approx \left[(h_2 - h_1)/d_0\right] 10^{-3} \text{ radians.} \qquad (4.4\text{-}9)$$

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* h_1 and h_2 are measured relative to a common reference elevation such as mean sea level.

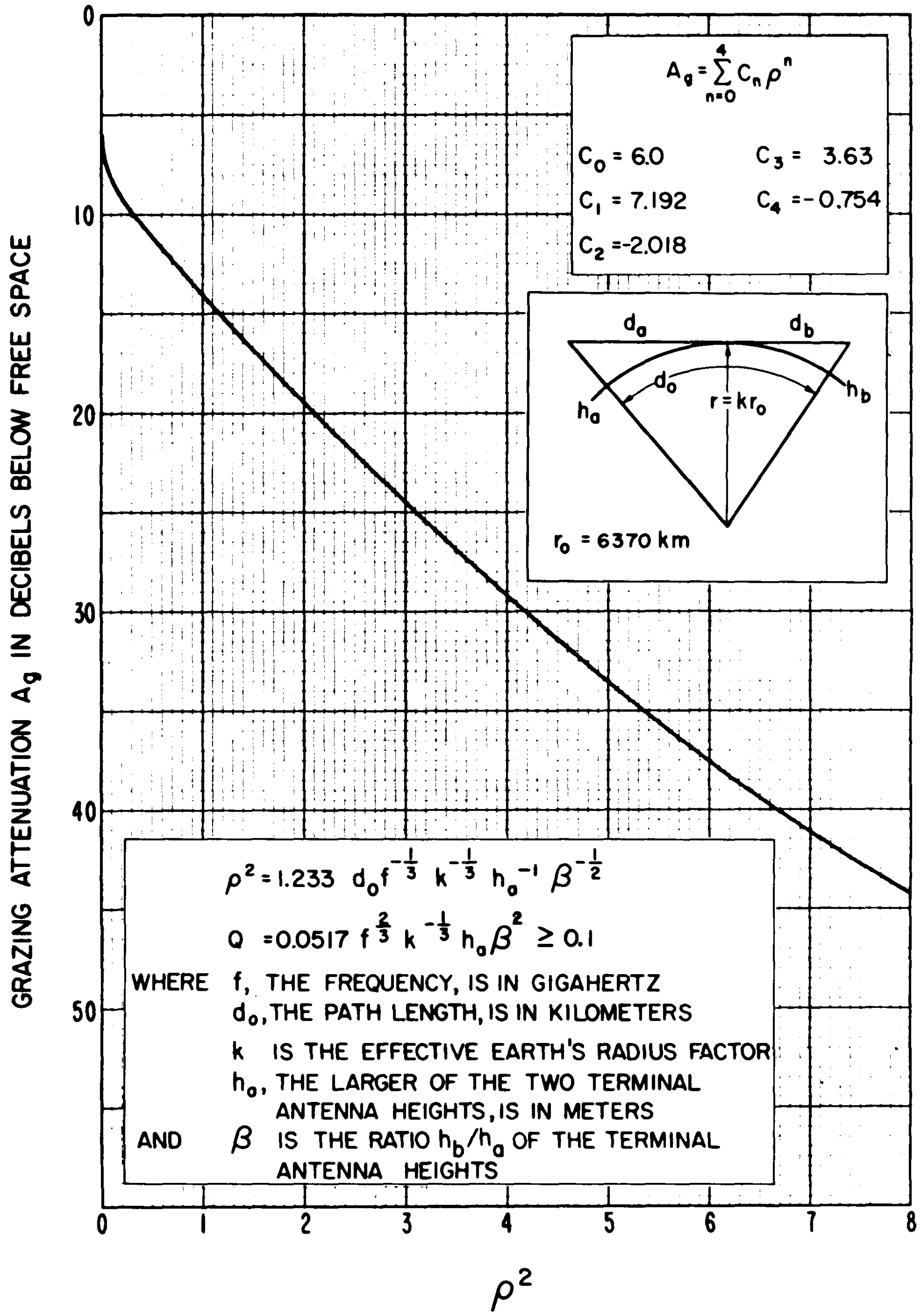


Figure 4.4-14 Attenuation of a Field Due to Diffraction by a Smooth Spherical Earth at Exactly Grazing Conditions and Relative to the Free Space Field

For situations that may be approximated by a linear gradient, k is given by (4.4-4) and the angle-of-arrival will be

$$\tan \theta_1(k) = -79 \times 10^{-6}[d_0/k] + \tan \theta_1(\infty), \qquad (4.4\text{-}10)$$

or

$$\theta_1(k) - \theta_1(\infty) \approx -7.9 \times 10^{-5}\, d_0/k \text{ rad.} \qquad (4.4\text{-}11)$$

For high gain antennas, super refractive conditions (negative k-values) will tend to enhance the reception of ground reflected rays, and subrefractive conditions (positive k-values less than unity) will tend to enhance the contributions from elevated layers, etc. This should be clear from (4.4-10), since k is positive and greater than unity for common design practice. Negative k-values then cause the angle-of-arrival to exceed that for which the antennas are oriented. Similarly, for 0 < k < 1.0, the angle-of-arrival is less than that for the design conditions.

4.4.14 Power fading due to ducts and layers

4.4.14.1 Power fading due to atmospheric ducts and elevated layers, (c.) and (d.) in 4.4.11.1 is characterized by fades of 20 dB and occasionally greater values. They may persist for hours or days, but tend to be less frequent during daylight hours. This type of mechanism is the likely source of many phenomena which have been termed space-wave fadeouts. The fading is not generally sensitive to small-scale (in-band) changes of frequency or of spatial position of the antennas, and cannot therefore readily be remedied by commonly used diversity techniques.

4.4.14.2 An elevated duct is sometimes a combination of elevated layers, such as the occurrence of a super refractive layer above a subrefractive layer, and has the effect of guiding or focusing the signal energy along it. The reverse can also occur; the combination of a subrefractive layer above a super refractive layer will defocus energy introduced within the combination of layers. For terminals within such a combination, the defocusing effect will produce a power fade.

4.4.14.3 Obviously, repositioning of one or both antennas can eliminate the problem -see the two lower diagrams of figure 4.4-11 -- and in some situations this is feasible, although major height changes may be required. For effective repositioning of the antennas, some information about layer characteristics (prevalence, thickness, height, etc.) is required. For example, the likelihood of isolation for long paths is reduced by locating both terminal antennas at the same height relative to the expected duct or layer position. For short paths, however, the likelihood of isolation can be reduced by a sufficiently great difference in antenna heights to insure that the angle of ray-path incidence at the elevated layer is at least on the order of a few degrees.

4.4.15 Fading due to precipitation

4.4.15.1 Power fading can also occur due to signal attenuation by extensive precipitation along a propagation path [20]. The effects of this fading can be lessened by route diversity which is the use of an alternate series of communication links [54], [63], and has been discussed in section 4.2.6.

4.4.16 Combinations of fading mechanisms

4.4.16.1 For many propagation paths, more than one fading mechanism will be involved, their relative significance changing with the refractive index. Two particular combinations that can be especially troublesome are k-type fading as described below, and surface-duct fading.

4.4.17 k-type fading

4.4.17.1 The k-type fading occurs for propagation over smooth or uniformly irregular terrain such as the sea surface, maritime terrain or gently rolling (pastoral) terrain. The mechanism involves either the multipath fading (direct ray plus ground reflections) or the diffraction type of power fading, depending upon the value of the earth-radius factor k [62]. The two mechanisms supplement one another and produce fading throughout a wide range of refractive index gradients or k-values. Resulting signal variations are illustrated in figure 4.4-15 which is a graph of the envelope of spherical-earth transmission loss versus refractive index gradient. It also shows the effect of terrain roughness (expressed here by the ratio σ/λ) and takes into account the divergence-convergence factor under the dynamic influence of the refractive index gradient. The ratio σ/λ is that of the standard deviation, σ, of the surface irregularities (about a median spherical surface) to the transmission wavelength, λ (both expressed in the same units). For a smooth earth ($\sigma/\lambda = 0$), the fading produced by the interference between the direct wave and the specularly reflected wave is serious only over a limited range of refractive index gradients. For the path parameters of figure 4.4-15 as an example, the fades due to the interference nulls can exceed 20 dB only within the range of -115 to -195 N units/km and for gradients in excess of 300 N units/km. As the surface roughness is increased ($\sigma/\lambda > 0$), the critical region Of gradients for 20 dB fades shifts to more negative values and becomes wider -- for $\sigma/\lambda = 10$. The graph shows a range of -180 to -290 N units/km. Irregularities or roughness that would cause the median terrain surface to depart slightly from a sphere could also shift the range of critical negative gradients in either direction. Naturally, these critical ranges, as well as the region of diffraction fading depend upon the specific link parameters (transmission frequency, antenna height, and path length) . One aspect should be clear from figure 4.4-15: unless the terrain roughness is sufficient to shift the critical range of negative gradients outside of the range of refractive index gradients expected to occur at a particular location (see figure 4.4-5 for example), reflections from the terrain surface cannot be considered to eliminate terrain reflection

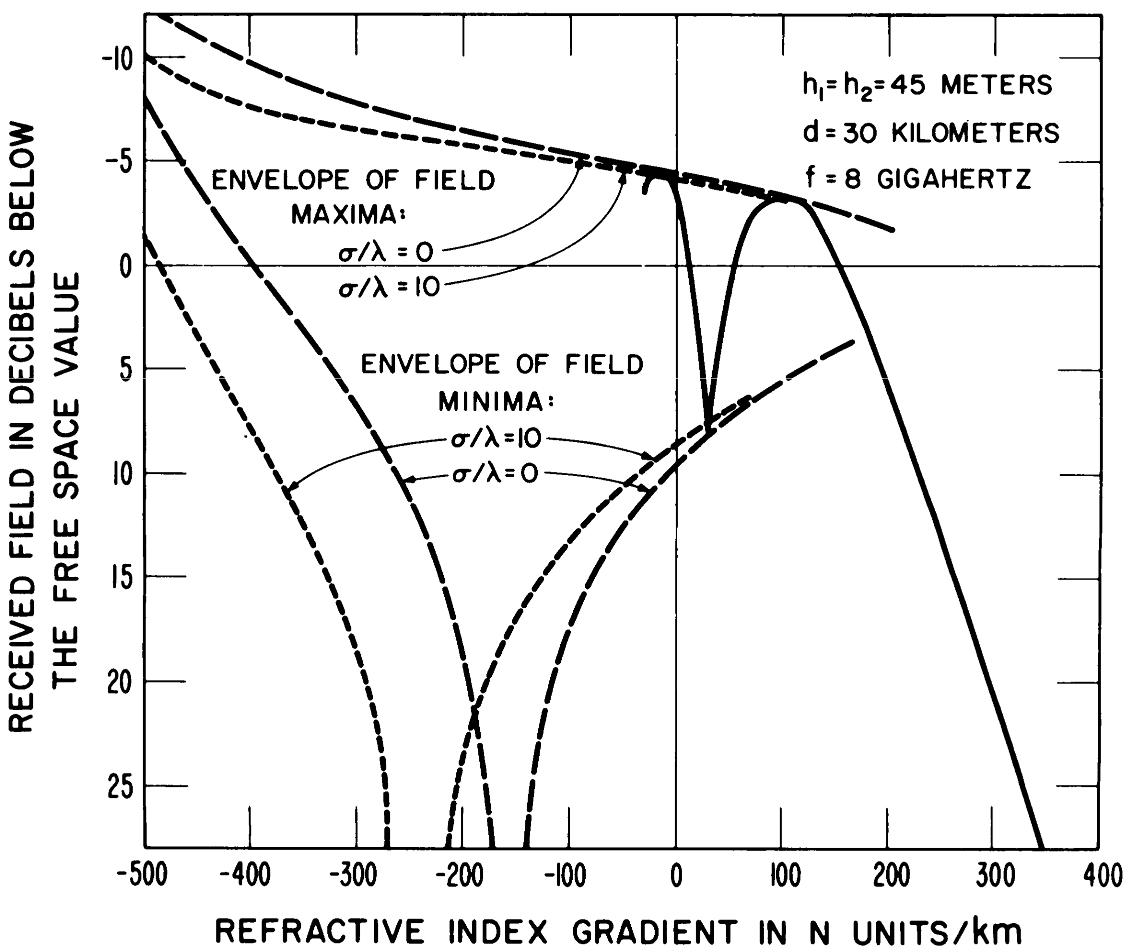


Figure 4.4-15 Illustration of the Variation of Field Strength with Refractive Index Gradient, k-Type Fading

unless they also partially obstruct the reflected wave over the critical range of refractive index gradients.

4.4.17.2 The effects of k-type fading are reduced by (1) increasing the terminal antenna heights to provide adequate protection against the diffraction fading for the expected extreme positive gradients of refractive index; and also (2) diversity reception that effectively reduces the attenuation due to multipath out to the expected extreme negative gradients of refractive index. An applicable design procedure was first proposed and demonstrated as reported in [59]. A more accurate extension of such design procedures is given in [49] and [67] .

4.4.18 <u>Surface duct fading</u>

4.4.18.1 Surface duct fading is encountered on long, line-of-sight, over-water paths. Sea surface ducts may constitute a semipermanent condition as, for example, in the region of the Bermuda High, a high--pressure region of the Atlantic between 10° and 30° N latitude. There, the ducts form less than 2 km from the shore and extend from the sea surface up to heights of 7 to 20 m for wind velocities from 15 to 55 km/hr. They persist during fair weather and reform after squalls and rain showers [57]. The corresponding fading mechanism is a combination of multipath fading (for reflections from the sea) and power fading in the presence of the sea surface duct. These two mechanisms are illustrated in figure 4.4-16. Because of the continual disturbance of the sea surface, a reflected wave consists of a diffuse or randomly distributed component superimposed upon the specular component, and its time distribution is a Beckmann distribution consisting of a constant component plus a Hoyt distribution [40], and [55]. This constitutes the received field for the upper diagram of figure 4.4-16. Addition of the direct wave, as in the situation illustrated by the lower diagram of figure 4.4-16, produces an enhanced or reduced constant component due to

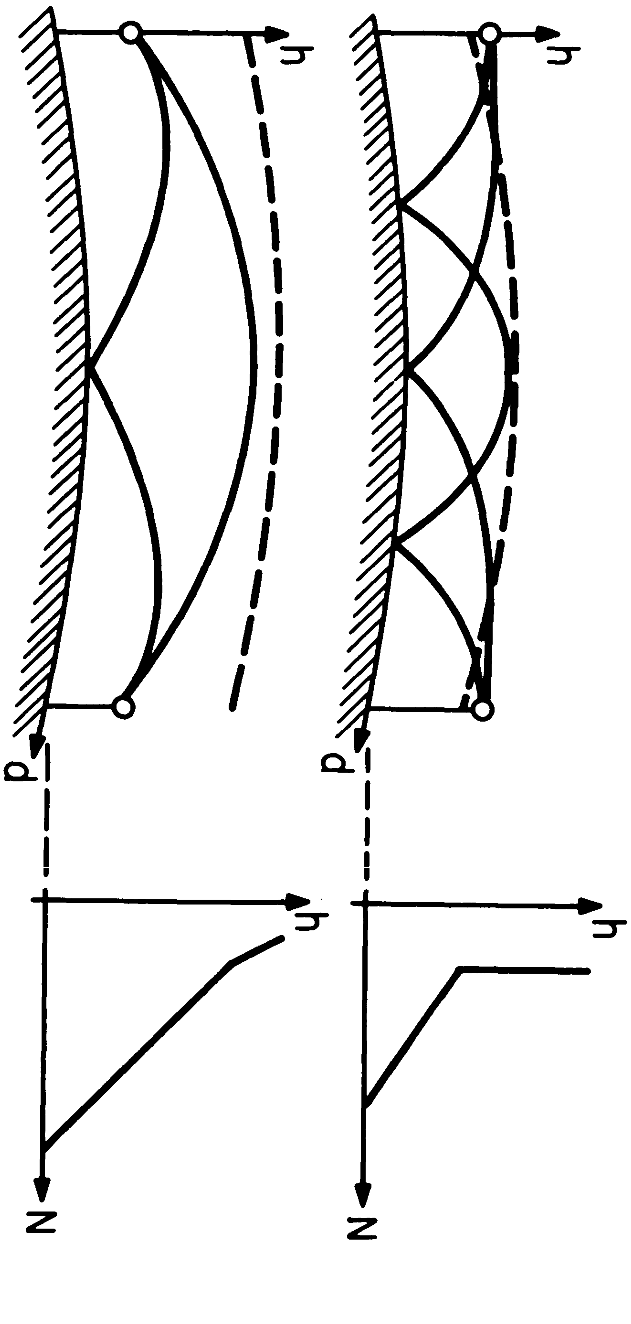


Figure 4.4-16 Surface Duct Fading Mechanism

phase interference. One effect of the surface duct upon the multipath situation is to provide an increased angle of incidence for the energy reflected from the sea surface. This reduces the reflection coefficient and thereby increases the ratio of the diffused to specular amplitudes, and increases the rapidly varying component of the reflected signal. The net result is a total signal whose distribution approaches the Nakagami-Rice distribution, a constant plus a Rayleigh-distributed variable [44], [65], [66], [67], and [71].

4.4.18.2 Surface or ground-based ducts guide or trap the radio waves by the combination of a strong negative refractive index gradient (superrefraction, $\Delta N/\Delta h \leq$ -157 N units/km) and a reflecting sea or ground. Propagation within the duct has been described in [53] resulting from an equivalent linear gradient of refractive index, and is illustrated on the right-hand side of figure 4.4-17. The field may result from phase interference between a direct wave and one to three singly reflected waves. For sufficiently strong super refraction, doubly reflected waves may contribute.

4.4.18.3 Surface-duct fading can also be reduced by means of a proper adaptation of procedure [59]. Choosing the initial terminal antenna heights to provide adequate Fresnel zone clearance (above the ducting layer) avoids the situation shown in the upper drawing in figure 4.4-16. Similarly, lower antenna heights could achieve the situation shown in the lower drawing of figure 4.4-16. In the latter case, diversity reception would also be required because of the multipath effect.

Multipath fading characteristics have already been described in section 4.4.10. In order to obtain distribution curves for the received signal level values one must first evaluate the amplitude and phase relations of the various multipath components.

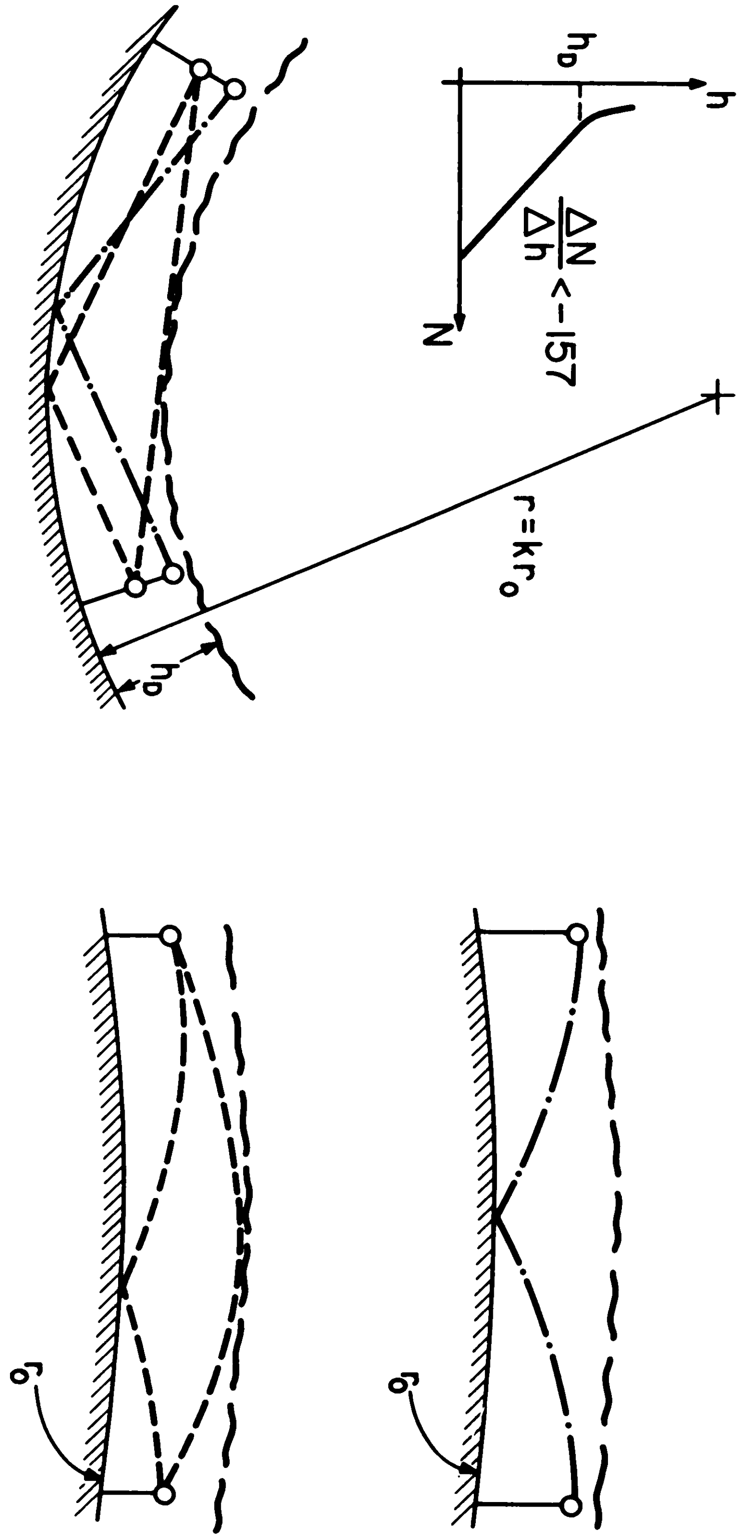


Figure 4.4-17 Examples of Surface Duct Propagation for Effective Earth Radius and True Earth Radius

4.4.19 The relative amplitudes of the multipath components

4.4.19.1 Theoretical and experimental studies of reflection and scattering from terrain have just recently resulted in engineering expressions that permit an estimate of the reflected and scattered components [41]. For the particular case of small angles of incidence and the microwave frequencies at which specular reflection from terrain results in significant fading, the Fresnel reflection coefficients modified by a divergence factor may be taken as essentially unity (with a 180° phase shift upon reflection). The specular reflection coefficient then becomes equal to the factor α [41]:

$$\alpha = \exp\{-m/2\}, \qquad (4.4\text{-}13)$$

where

$$m = [4\pi \frac{\sigma}{\lambda} \sin \theta]^2. \qquad (4.4\text{-}14)$$

Here, σ is the standard deviation of the irregular terrain about its mean elevation (as before), λ is the transmission wave length, and θ is the angle of incidence (zero for grazing conditions). σ and λ must be in the same units. The expression for m is recognizable as related to the Rayleigh criterion for roughness (see paragraph 4.2.19.2). The specularly reflected component is therefore given $\alpha\sqrt{g}$, where g is the geometric mean of the transmitting and receiving antenna power gain values (as ratios, not in dB) for the reflected ray path relative to those for the direct path. In addition to this specularly reflected component, there is the random field scattered by the irregularities of the atmosphere and/or the reflecting terrain. The rms value of this non-specularly reflected component depends upon the reflecting surface's distribution and correlation function, but is almost always appreciably less than

$$[g - \alpha^2]^{\frac{1}{2}}. \qquad (4.4\text{-}15)$$

4.4.20 The received signal amplitude distributions

4.4.20.1 In general, the multipath fading mechanisms produce two or more components with varying relative phases. Even when several components are involved, one or two of them tend to be dominant. For this reason, one would generally not expect a Rayleigh-distributed received signal. The departure from a Rayleigh distribution will take one of two forms, depending upon the nature of the field components.

4.4.20.2 For grazing angles of more than a few milliradians, the specularly reflected wave tends to be small, while the randomly (non-specularly) reflected components tend to provide a significant contribution. The signal distribution tends to be less steep than a Rayleigh distribution; it consists of a constant direct signal plus a random signal [42], and [66]. The resulting family of cumulative distributions, adapted from [40] and [41], is illustrated in figures 4.4-18 through 4.4-22 as a function of the parameters B and K. These distributions give the percent of the time that the total field strength r will exceed its rms value $\tilde{r}$ by an amount given by the vertical decibel scale expressed by

$$Z = 20 \log_{10}(r/\tilde{r}). \qquad (4.4\text{-}16)$$

4.4.20.3 The ratio of the constant component (the direct field) to the RMS value of the random field is indicated by B on the distribution curves. The parameter K is a measure of the anisotropic scattering of the random components by the terrain. For a very rough reflecting or scattering surface, the phases of the random components are uniformly distributed and K^2 is unity. For less rough surfaces, such as the sea in fair weather or rolling, pastoral terrain, the pattern of roughness differs with direction and K^2 departs from unity. The distribution of the randomly reflected or scattered components may be represented by that for the vector sum of two orthogonal random components -- a Hoyt

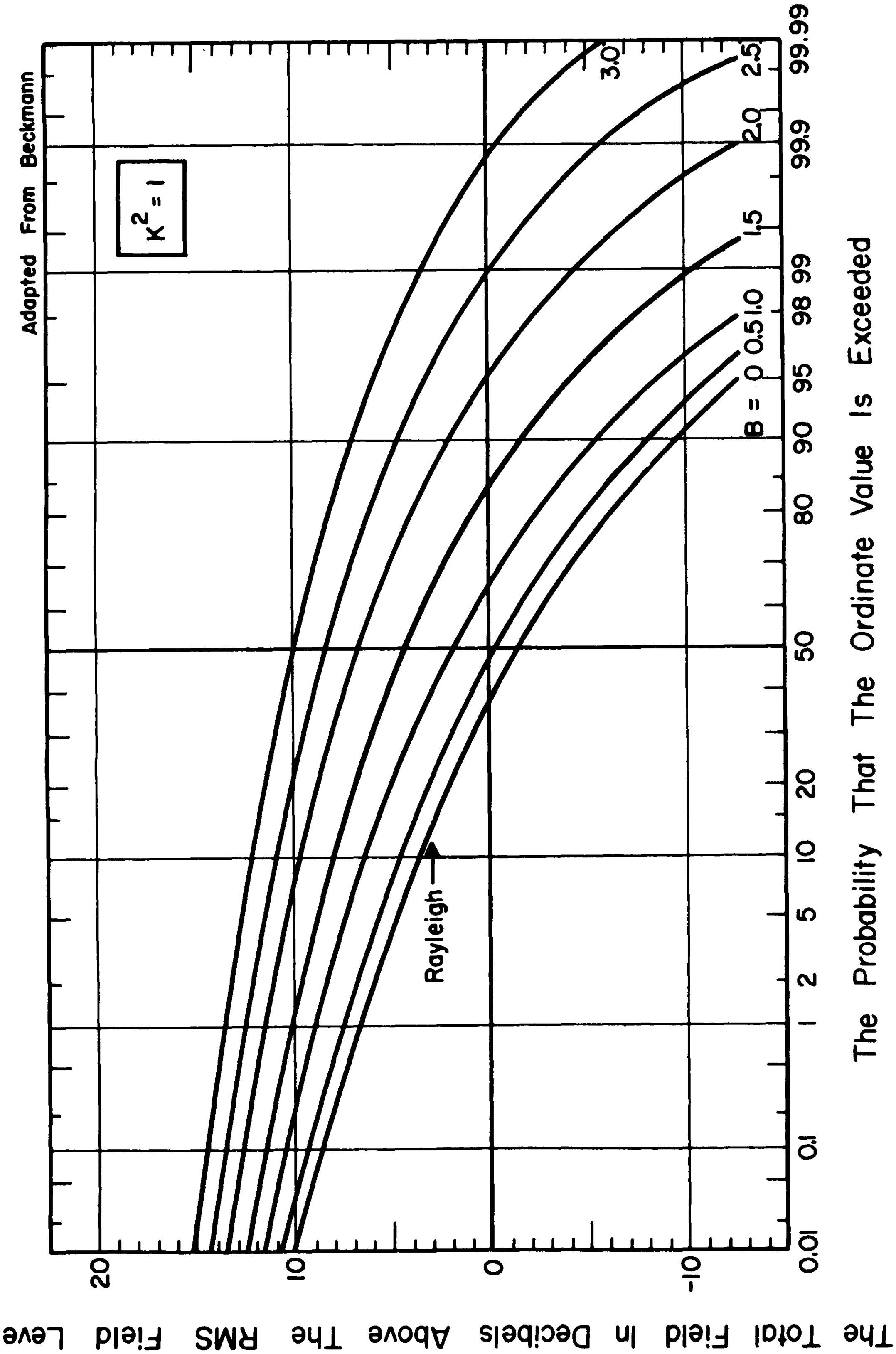


Figure 4.4-18 The Amplitude Distributions for a Constant Component plus a Rayleigh Distribution

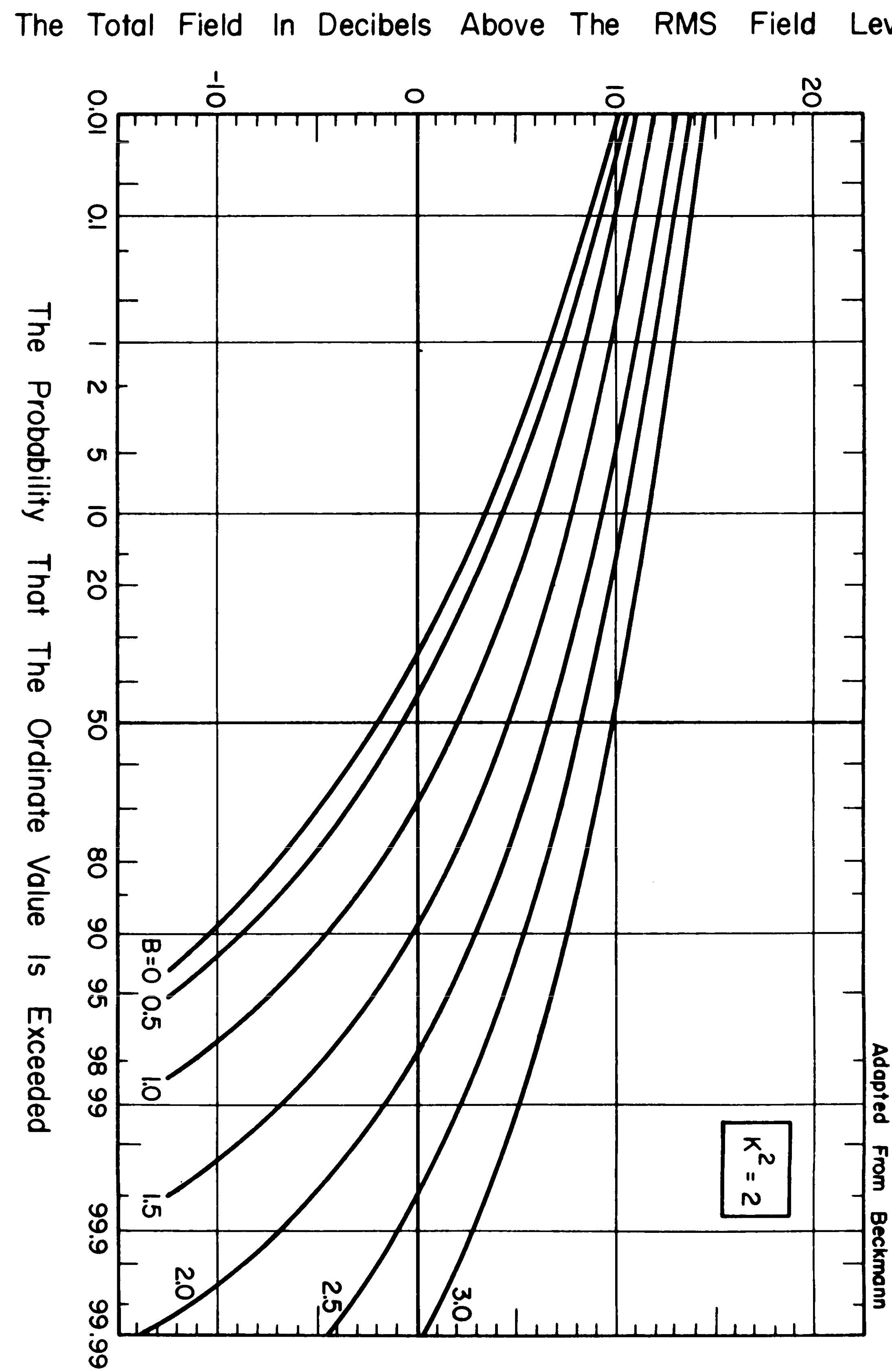


Figure 4.4-19 The Amplitude Distributions for a Constant Component plus a Hoyt Distribution where $k^2 = 2$

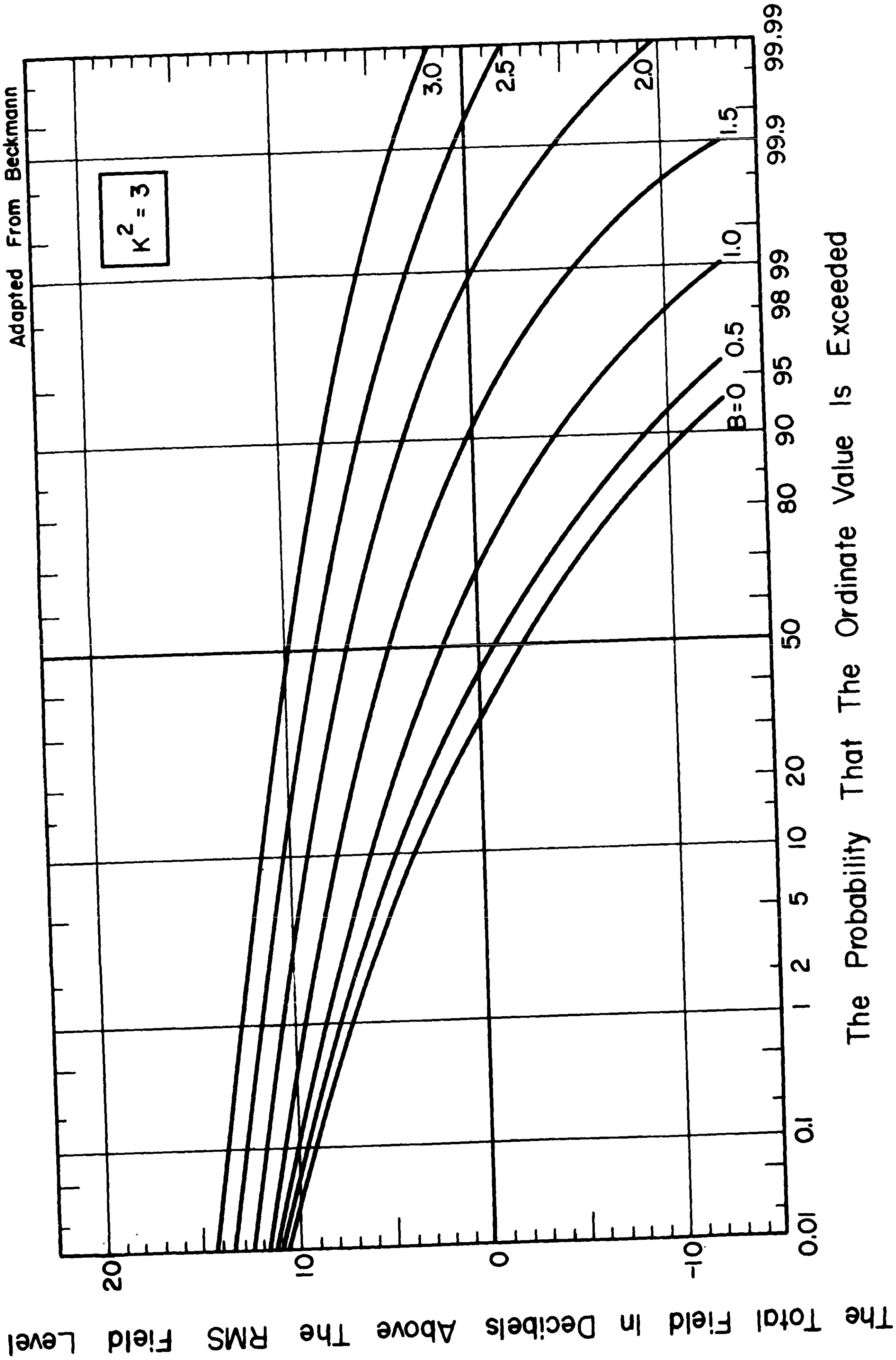


Figure 4.4-20 The Amplitude Distributions for a Constant Component plus a Hoyt Distribution where $K^2 = 3$

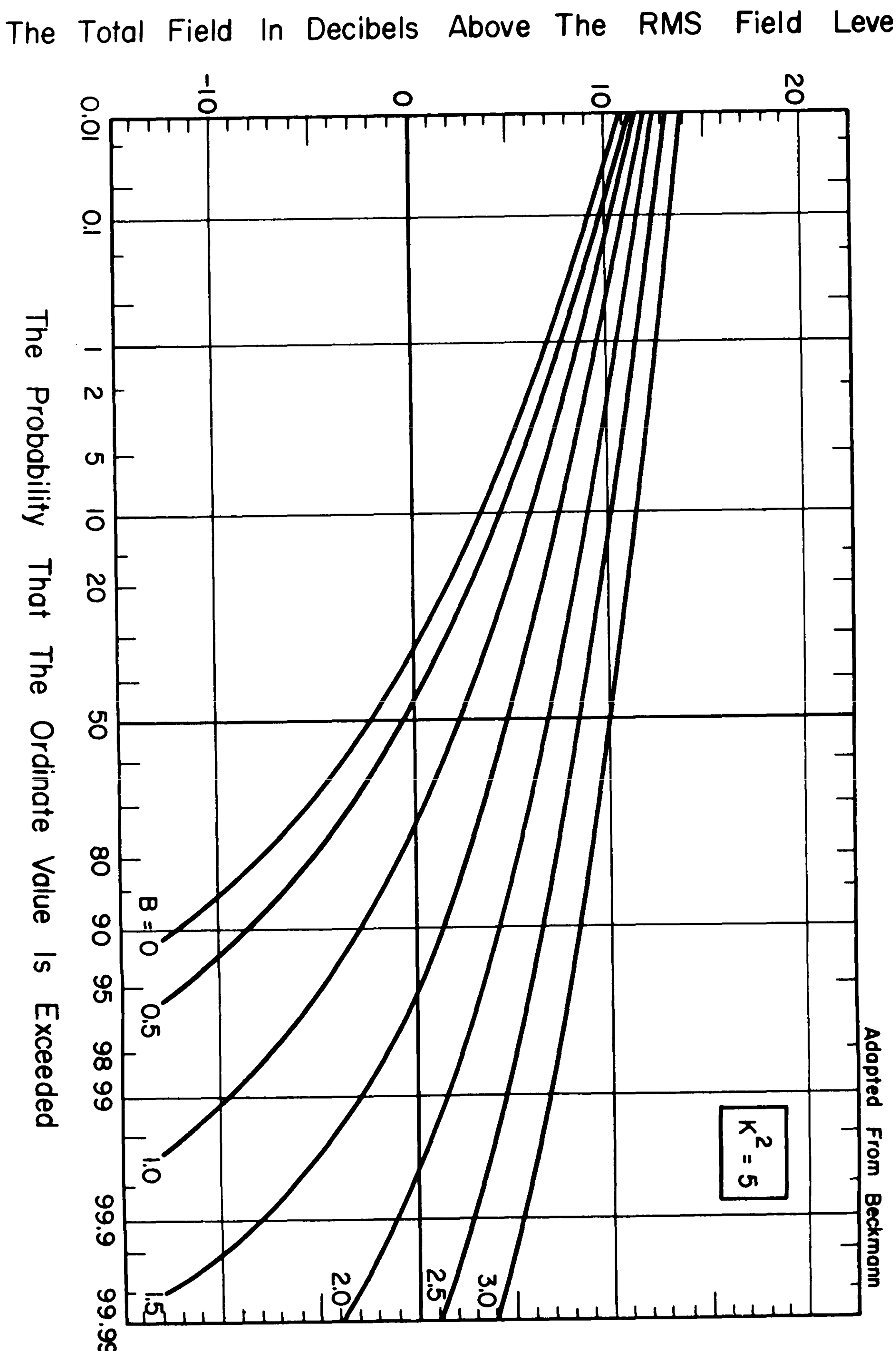


Figure 4.4-21 The Amplitude Distributions for a Constant Component plus a Hoyt Distribution where $k^2 = 5$

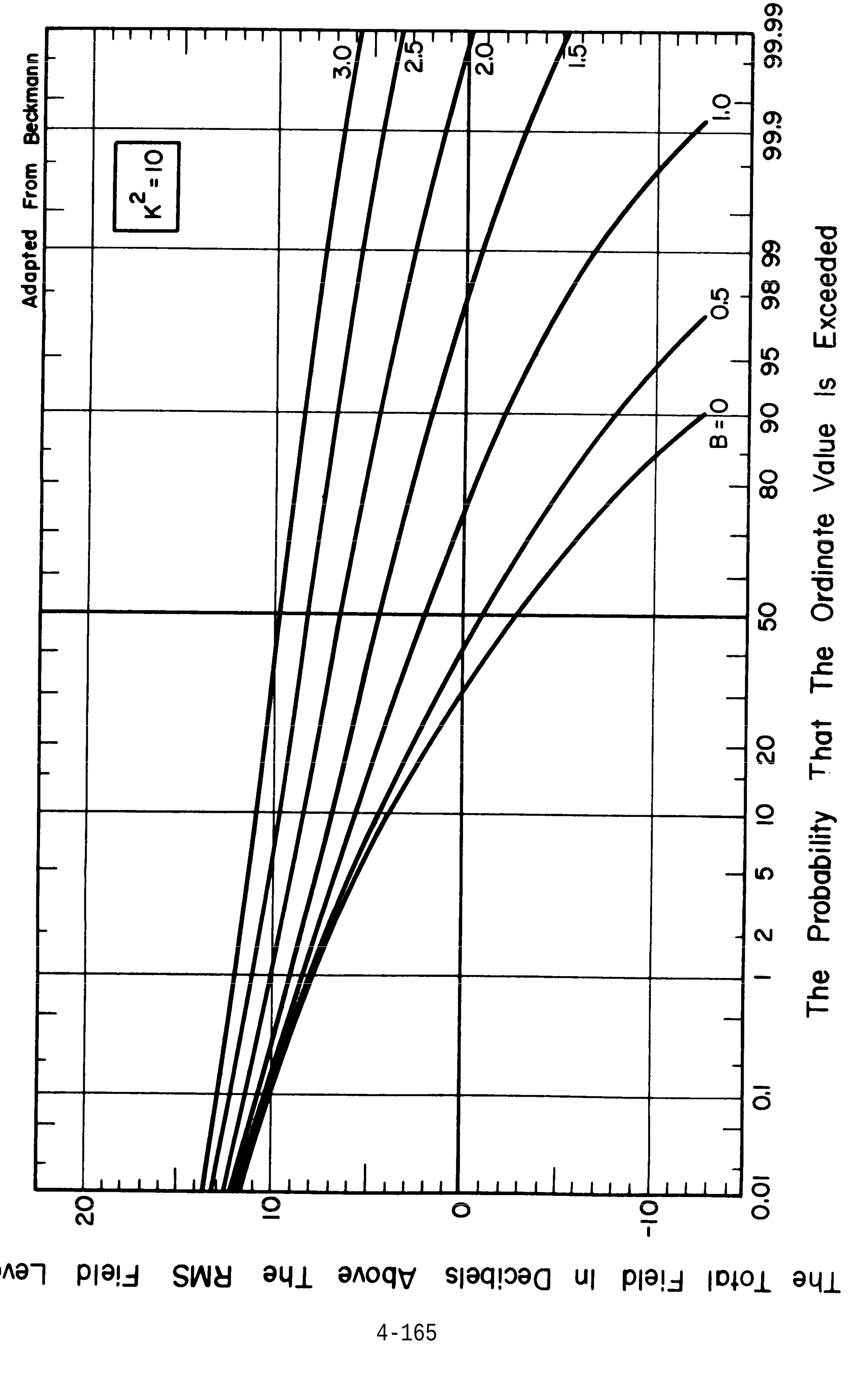


Figure 4.4-22 The Amplitude Distributions for a Constant Component plus a Hoyt Distribution where $k^2=10$

distribution. Each component has an amplitude that is normally distributed about a mean of zero and the K^2 is the ratio of the variances of the two distributions.

4.4.20.4 If there is no constant (direct field) component, then B = 0, and the total field distribution reduces to that for the random components, a Hoyt distribution [42], and [55]. If, in addition, the surface is extremely rough so that K^2 is unity, the distribution reduces to a Rayleigh distribution, as in figure 4.4-18 with B = 0. The distributions of figure 4.4-18 for B > 0 are also known as the Nakagami-Rice distribution [44], [66], [67], and [71].

4.4.20.5 Note that the sum of a direct field and many randomly reflected components will produce distributions similar to those given by figures 4.4-18 through 4.4-22. The distribution, however, actually implies only that the sum is that of many random components, one of which is constant and dominant for large values of B; it does not imply that the components have to be reflections. A variety of alternate presentations of the information in figure 4.4-18 through 4.4-22 is given in [40].

4.4.20.6 For very small grazing angles the reflected wave is essentially given by the specularly reflected component. The cumulative signal distribution caused by interference between the direct wave and this specularly reflected component tends to be steeper than a Rayleigh distribution for strong specular reflection. The resultant two-component multipath distribution are given in figure 4.4-23 for various values of the reflector coefficient α, and the rms field for each case is therefore $\sqrt{1 + \alpha}$ [50]. The total field is indicated in terms of decibels relative to this rms value. Similar curves are given in [70]. Again, these distributions do not necessarily imply a direct wave plus a specularly reflected component from the terrain; they merely imply two constant

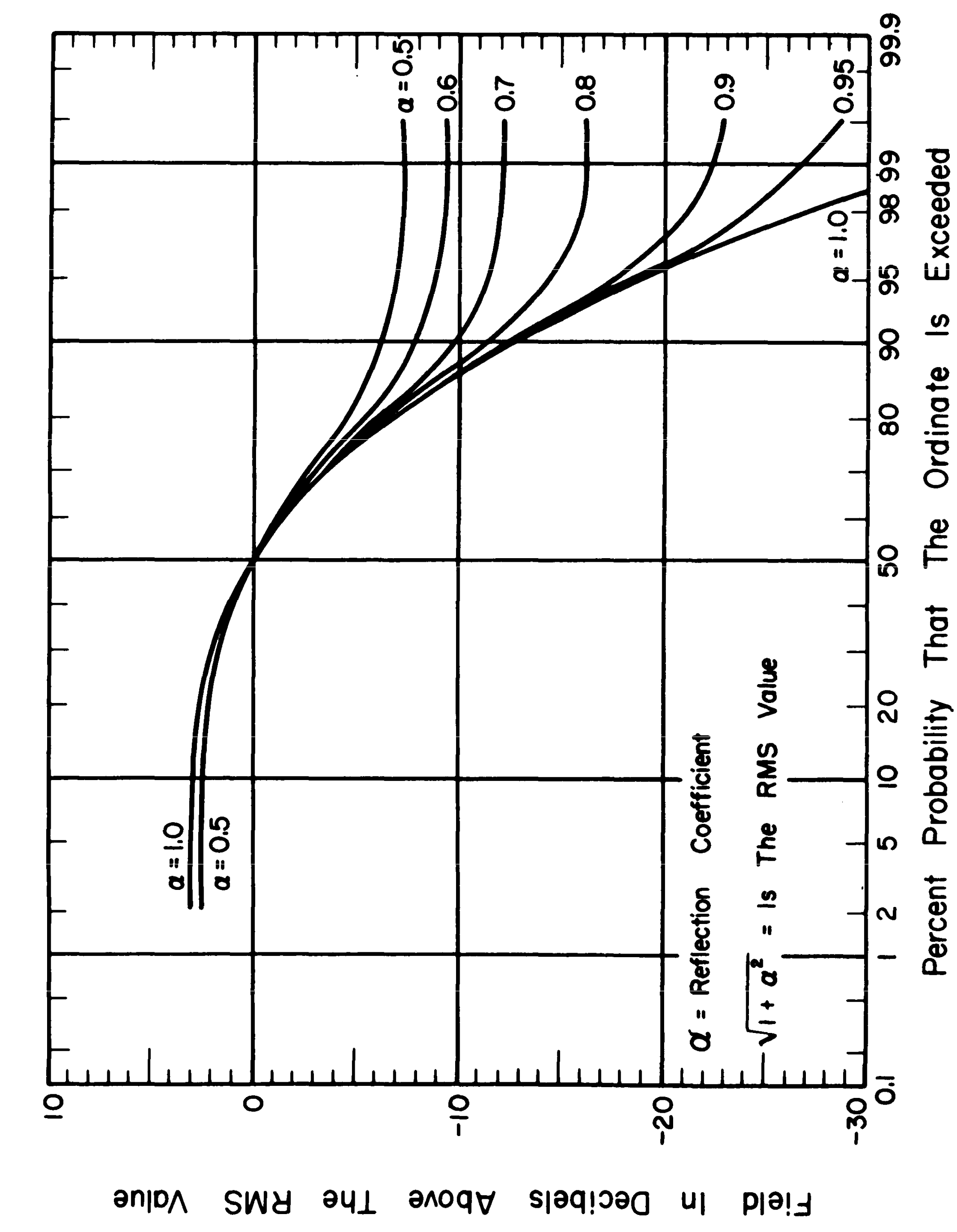


Figure 4.4-23 The Distribution for Two-Component Multipath
(Direct plus a Reflected Field)

components with a uniformly distributed difference in phase. Hence figure 4.4-23, as well as 4.4-18 through 4.4-22, describes conditions that may be due to any of the multipath fading mechanisms, and additional information is usually required to distinguish between such mechanisms.

4.4.20.7 The most general situation, occurring for moderately small angles of incidence, involves two constant components (direct wave plus the specularly reflected wave) and a randomly distributed component (caused by nonsecular reflection and atmospheric scattering). A complete family of such cumulative distribution curves has not been computed, but an illustrative example is taken from [50] presented in figure 4.4-24. There , α, as previously defined, equals unity, and the rms random field value is indicated by S in decibels above the two-component rms value, $\sqrt{1 + \alpha^2} = \sqrt{2}$. Again, the total field r is expressed in decibels relative to the total rms field value $\tilde{r}$.

4.4.20.8 In some of the foregoing distributions, an *a priori* determination of the signal distribution from the parameter value depends upon an estimate of the mean power in the random component. In the case of terrain reflections, an estimate may be obtained from the distribution and correlation function of the terrain irregularities [41]. However, these are also often unknown. Frequently, a knowledge of the parameters is not necessary; it is usually sufficient to know which family of distributions is expected. Alternately, one may be interested in comparing observed distributions with those of figure 4.4-18 through 4.4-22, so that the likely fading mechanisms may be inferred.

4.4.21 Path fading range estimates

4.4.21.1 Atmospheric considerations. Satisfactory methods of estimating fading probability on specific paths from climatological statistics are not available at present. Statistical studies of

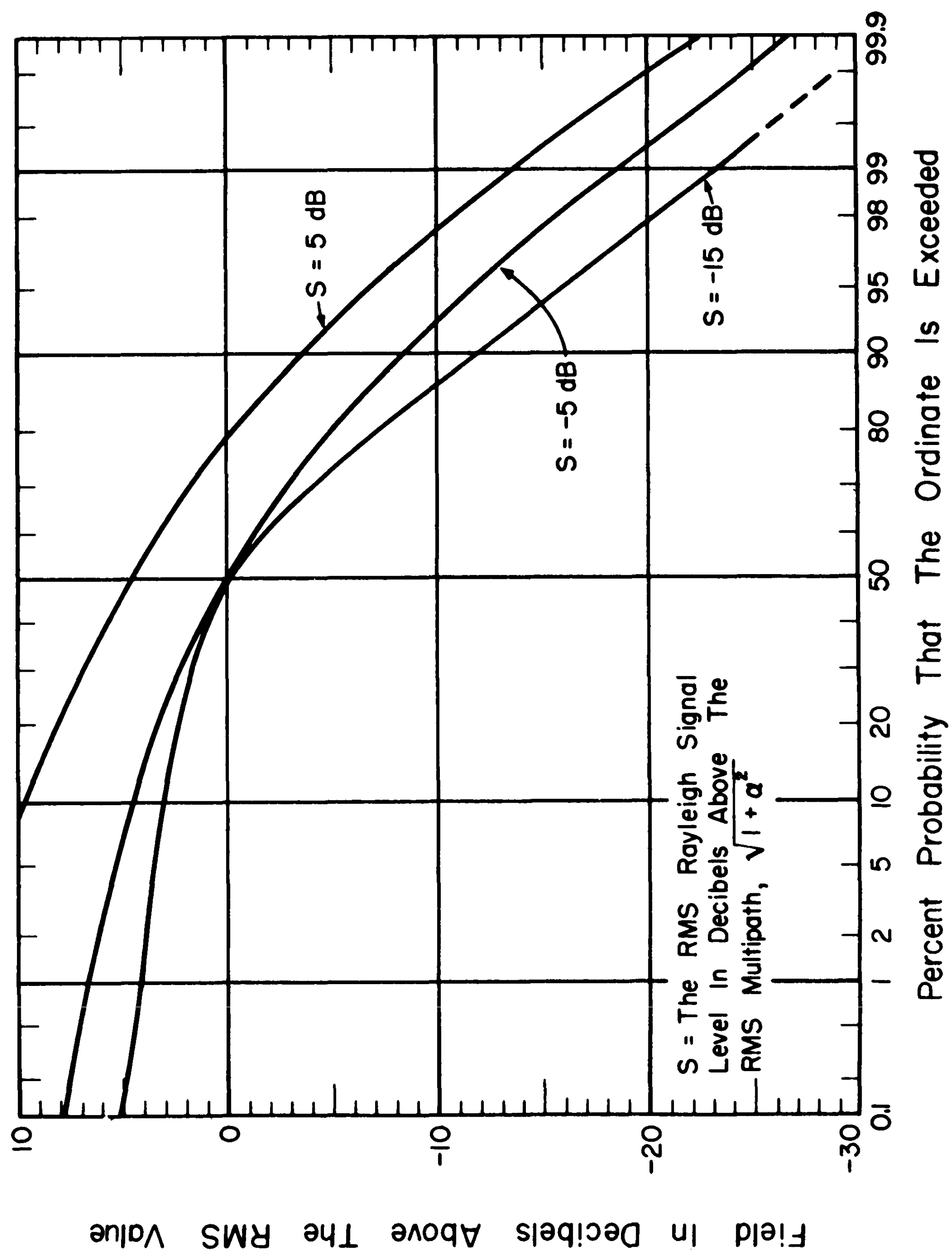


Figure 4.4-24 The Distribution for Two-Component Multipath (α = 1.0) plus a Rayleigh Distributed Signal

refractivity can, however, provide information on relative gradient probabilities for different areas, and indicate the seasonal changes to be expected [39]. The low-level refractivity gradients that are of most importance to line-of-sight propagation are very sensitive to variations in the local surface conditions, and therefore the information obtained on the site surveys can be useful at this stage of link design. Operating experience on many microwave links shows that:

a. Fading is more likely on paths across flat ground than on paths over rough terrain;

b. There is less fading on paths across dry ground than on paths across river valleys, wet or swampy terrain, or irrigated fields;

c. Calm weather conditions are favorable to the atmospheric stratifications that may result in deep fading; these conditions occur more often in broad, protected river valleys than over open country;

d. Fading is likely near the center of large, slow-moving anticyclones (high pressure areas). These are more likely to occur in summer and fall than in winter and spring;

e. Fading occurs more frequently and is more severe in summer than in winter (in temperate climates);

f. Paths with takeoff angles more than about 0.5° are less susceptible to fading, and the effect of refractivity gradients is negligible for takeoff angles above 1.5° [45].

The empirical method outlined in section 4.2.27 is recommended for obtaining path fading probability estimates.

4.4.21.2 As an example of the use of this method, consider a 50 km path over flat terrain in a relatively humid region, operating at 6 GHz with a 40 dB fading margin:

$$P_{mf} = a \times b \times 6.0 \times 10^{-5} \times f \times d^3 \times 10^{-M_f/10}\%$$

$$= 4 \times \frac{1}{2} \times 6.0 \times 10^{-5} \times 6.0 \times 50^3 \times 10^{-40/10}\%$$

$$= 0.009\%$$

(see eq. 4.2-22 from section 4.2.27)

Therefore, fading exceeding the margin of 40 dB is estimated to occur during about 0.009% of the year, or 47 minutes. If higher reliability is required, some change in path parameters will be necessary. Possible diurnal variations in circuit loading should also be considered, since on overland paths fading occurs about 5 times more frequently at night than in the daytime [3]. Thus in the example above we might expect only about 8 minutes of the fading to occur during the daylight hours.

4.4.22 Diversity on microwave relay links

4.4.22.1 A reliable microwave system can be made into an extremely reliable one if proper protective actions are taken. There are many discussions in the literature about reliability and how to improve it for example in [4] on page 110 to 117.

4.4. 22.2 Throughout this literature, the key word is redundancy. For example, outage due to equipment failure can be almost completely eliminated if redundant equipment is available and if a proper maintenance procedure is used. Similarly, to combat outages due to anomalous propagation, one looks for redundant propagation paths.

4.4. 22.3 The most drastic way in which to supply this latter redundancy is to provide the system with two, or even more, distinct sets of relay links which traverse entirely different routes. At the receiving terminal, there are then available two or more signals which carry the same information but which have undergone degradation of different amounts at different times. By "combining" these signals (often by merely switching to the one that is momentarily the best) one can obtain a more nearly perfect reproduction of the original information. Because of the diverse routes involved, this technique is called route diversity. In a restricted sense (restricted, because no dynamic switching is involved), this is what long-haul lines of a common carrier are likely to use. The technique has also been suggested [54] as a very practical way to combat precipitation fading at millimeter waves.

4.4.22.4 The almost universal practice, however, is to use but a single route and to attempt to make each link of that route as reliable as possible. Earth bulge fading, for example, is combatted by carefully choosing antenna heights large enough so that the direct ray clears all potential obstacles, even under the most adverse subrefractive conditions.

4.4.22.5 Space-wave fadeouts and other forms of power fading can be combatted by specifying a sufficiently large fade margin by which the normally received signal level exceeds the minimum for satisfactory performance. Although fade margins as low as 20 dB were sometimes used in the past, today most links are designed to have fade margins of 35 to 40 dB or more. These high signals, incidentally, are provided for more reasons than merely to protect against fading. If frequency modulation is used, and if the system is composed of many links, the same fade margins are also needed to meet basic system noise objectives (sect. 4.5.16). Fading, when it occurs, will most probably effect only a single link. Although a 20 dB fade on one link will affect total system noise only slightly, the same drop in signal level on all links will introduce unacceptable noise levels in the system.

4.4.22.6 These first precautions have the highest priority. If, for one reason or another, it is impossible to provide high enough antennas or large enough fade margins, the engineer must either look for an intermediate relay point or resign himself to the consequently lessened reliability.

4.4.22.7 For still higher degrees of reliability, specular and non-secular multipath fading must be considered. Since these are caused by the destructive interference of two or more waves, an interesting situation presents itself. A change in the phase relation between these waves may change the destructive interference to constructive interference. This, of course, actually happens as the atmosphere changes with time and causes the received signal level to go above and below a given reference value. On an instantaneous basis, the required change in phase can be accomplished in two ways. One way is to change the carrier frequency, using the fact that the relative phases involved are linear functions of frequent y. The second way is to remember that a multipath field implies an interference pattern in space, so that a small change in position of the receiving antenna will also change the relative phases.

4.4.22.8 These observations lead to the techniques of frequency diversity and space diversity. In the first, the same message is transmitted on two different frequencies. At the receiving terminal, both signals are received, amplified, and then combined (perhaps by switching to the better) assuming that if one fades out, the other will not.

4.4.22.9 When space diversity is used, there is only a single transmission, but at the receiving terminal this transmission is picked up by two different antennas. For both theoretical reasons and convenience, it is best to space these vertically along the antenna tower. Then the two received signals are amplified and combined, again under the assumption that if one of them fades out, the other will not. Figure 4.4-25 and 4.4-26 are simplified block diagrams which show how these two techniques might be implemented.

4.4.22.10 It should be emphasized that neither frequency nor space diversity will combat power fading because power fading may affect the entire microwave spectrum and large regions of space. When such fading appears on one received channel, it is most likely to appear simultaneously on the other.

4.4.22.11 On the other hand, a large fade margin does help to combat both power fading and multipath fading. In general, the deeper the fade the more rare is its occurrence. Thus, the larger the fade margin, the more rarely will it be exceeded.

4.4.22.12 There are other protective actions that might be taken. Polarization diversity is often mentioned, but is of little use. It would presumably entail receiving and combining signals on two orthogonal polarizations. However, at microwave frequencies the two polarizations are affected by the atmosphere in almost identical ways. If one of these channels fades out, so will the other. (Orthogonal polarizations are often used in frequency diversity systems, but only as a device to provide added isolation of the two channel s.) Angle diversity and mode diversity have been tried with some success. They both resemble space diversity, but use more compact arrangements for the two received channels. (Angle diversity uses two feed points on the same parabolic dish, while mode diversity depends on the excitation of a secondary mode in the wave guide leading to or from a large horn antenna.)

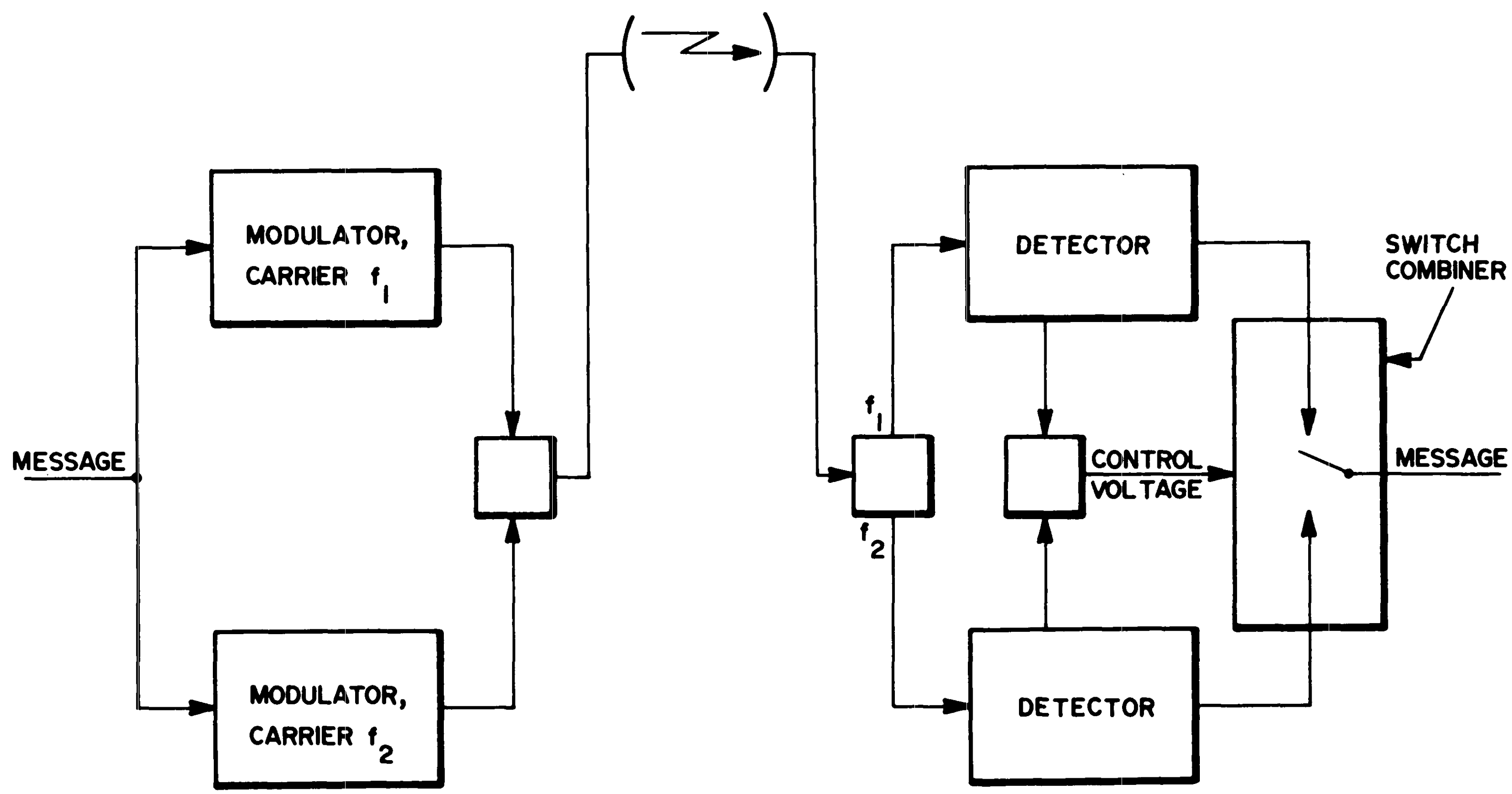


Figure 4.4-25 Simplified Block Diagram of a Frequency Diversity System

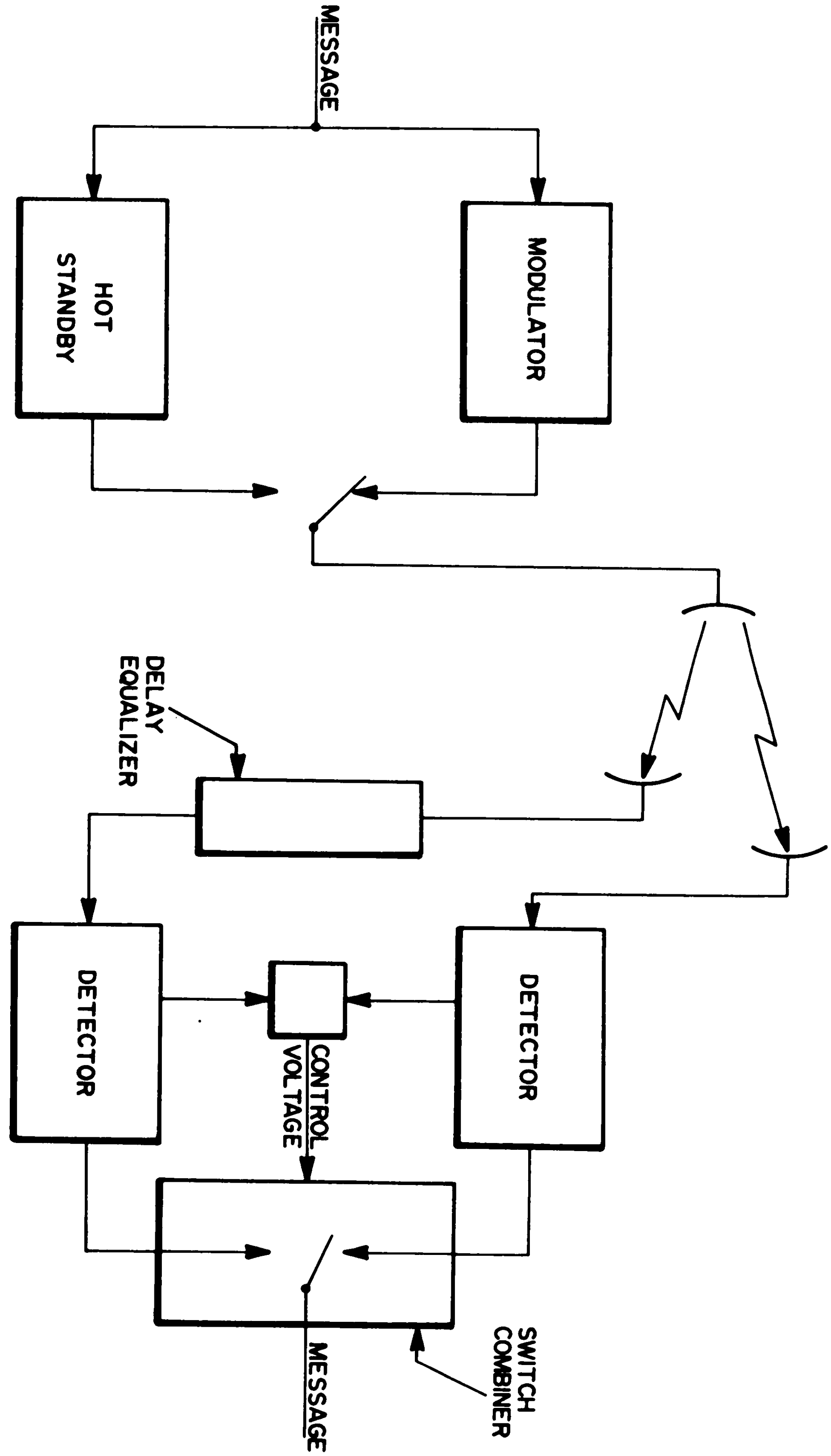


Figure 4.4-26 Simplified Block Diagram of a Space Diversity System

4.4.22.13 The term t<u>ime diversity</u> has several meanings. In its simplest form, the message is merely sent twice at different times. In a more complicated form the message is broken into components and each component is sent at delayed times. Of a similar nature are various coding techniques. When pulse modulation is employed, redundant or error-correcting codes can be used. Indeed, such techniques are almost mandatory for high-speed data transmissions. In this regard, it should be remembered that multipath fading implies the existence of multiplicative noise which may already render a pulse system inoperative irrespective of any accompanying fades. Another way to say this is to note that the frequency selectivity, which is a characteristic of multipath fading and upon which frequency diversity is based, may make itself apparent within the channel itself, particularly if that channel occupies a wide band. This situation implies frequency distortion within the channel which must be countered by other means.

4.4.22.14 The bulk of today's communication systems, if they use diversity at all, use either frequency or space diversity.

4.4.23 A comparison of frequency and space diversity

4.4.23.1 As illustrated in figures 4.4-25 and 4.4-26, and diversity system requires a duplication of equipments is therefore a rather expensive proposition, and should be considered carefully. There are many systems where the added reliability is unnecessary, and many paths over which fading is extremely rare. In such situations, diversity is an unneeded expense.

4.4.23.2 This argument, however, can be turned around. If it is thought necessary to provide redundant equipment as a protection against failure, then one might as well use diversity, too. The added expense will now be negligible, and the added reliability might be very welcome.

4.4.23.3 If it is determined that diversity is to be used on a given link, there still remains a decision to be made regarding the type of diversity to be employed. As indicated above, the choice, with only minor exceptions, will lie between frequency and space diversity. Some of the relative advantages of these two types will be discussed in the subsequent paragraphs.

4.4.23.4 It can be shown [68], and [75] that space diversity is preferable on microwave links, and this has been borne out by the limited experimental results that are available [36], [51], and [59]. The introduction of hybrid diversity systems is perhaps indicative of the advantages of space diversity. In a hybrid system, transmission is on two frequencies and the reception of these two frequencies is done with two vertically spaced antennas, thus providing a combination of frequency and space diversity. However, most of the existing hybrid systems [51], and [68] were not really designed in this manner -- they were originally built as frequency diversity systems and later modified to include the spaced antennas because of poor performance. However, the overall advantage of space diversity includes additional considerations.

4.4.23.5 The obvious disadvantage of frequency diversity is that it requires twice the spectrum space. The use of microwave relay systems is becoming so popular that this is a severe disadvantage. Indeed, the spectrum has become so crowded that the Federal Communications Commission in its Notice of Proposed Rule Making, denied the use of frequency diversity in the private microwave services and discouraged it elsewhere. In its announcement of May 27, 1971, it went a step further and denied its use to common carriers unless used in a multiple channel system with one protective channel for at least three working channels. The IRAC, too, discourages the use of frequency diversity.

4.4.23.6 On the other hand, space diversity is more expensive than frequency diversity because of the second antenna and the additional wave guide that must be provided. Often, the supporting tower must be built stronger because of the added weight. Also to be mentioned is the RF power switch that must be provided for the "hot standby" transmitting stage. This is more expensive and less reliable than the diplexer needed for the frequency diversity system.

4.4.23.7 If, in a space diversity system, the hot standby transmitter is eliminated in the interest of economy, the cost is reduced to almost exactly that of a frequency diversity system. But usually this is a false economy because in most systems the component of a relay link which is most likely to fail is not the propagation path, but the final RF stage in the transmitter. It follows that first priority in improving reliability belongs to the hot standby. An exception might be a system in which extremely high reliability is not needed, but in which one link is particularly prone to multipath fading. In such a case, the priorities are changed, and space diversity without a hot standby transmitter may be recommended.

4.4.23.8 A second oft-quoted advantage of frequency diversity is that it provides, ipso facto, two complete end-to-end electrical paths, so that full testing can be done without interrupting service. Such testing, of course, can be carried out during normal periods when there is little chance of fadeouts. Speaking more generally, frequency diversity provides a spare channel over which low priority information (such as a test signal) can be sent. The amount and importance of such traffic may determine whether the spectrum is used efficiently in such a case.

4.4.23.9 The TD-2 equipment of the Bell System [15] is a good example of how frequency diversity can be used efficiently. It is designed for heavy traffic routes and, in its original form, employs six different radio frequency channels of which only five are high priority "working" channels. A route is divided into sections of several individual hops each. At the end of each section the six channels are monitored, and when the noise on a working channel exceeds a given level, instructions are transmitted back to the beginning of the section where that channel is switched to the sixth, or "protection" channel. This makes up what is called a 1-for-5 frequency diversity protection, and is a very practical and efficient way of providing both equipment and propagation protection on a multiple channel system. In addition, the sixth channel is often used for low priority messages such as the transmission of video tape recordings. The monitoring and switching equipment is, of course, an added complication that must be borne by the system.

4.4.24 Engineering considerations

4.4.24.1 The design of space diversity systems requires a determination of the spacing between the diversity antennas. Because of the complexities of the mechanisms involved there may not always exist an optimum s pacing at which the diversity system would operate best under all conditions. Optimum spacings can at present only be calculated for very special conditions; e. g., smooth reflecting surfaces and a range of constant refractivity gradients [35], and [59]. This situation is sometimes held to be a disadvantage of space diversity.

4.4.24.2 The same problems exist in the selection of optimum frequency spacing for frequency diversity systems. However, in this case the choice is not determined by considerations of performance but by the currently applicable rules of spectrum management. Consequently, there is a relative advantage to space diversity because engineering considerations can be used to determine and optimize spacing at least in some cases.

4.4.24.3 Several methods and rules have been suggested [4], [7], [61], and [68] to select the proper vertical separation between space diversity antennas. Some of these are very complicated and depend critically on the path geometry and the meteorological climate. But it should be remembered that any diversity spacing will probably perform well, so that the rule of thumb which puts the spacing at 200 wavelengths or greater between antenna centers is adequate [4] p 58. Only in special circumstances (for example, when ground or sea reflections are involved) more complicated methods need to be considered. It might be well to add that poor performance on an installed space diversity link may be corrected simply and inexpensively changing the spacing, while converting a frequency diversity system to a hybrid one is much more costly.

4.4.24.4 In the case of frequency diversity, the common rule of thumb requires a frequency separation of at least 5% of the carrier frequency. However, TD-2 equipment described in 4.4.23.9 may use separations as small as 0.5% of the carrier frequency. This farther supports the already stated considerations that: (1) the choice of frequency separations is largely determined by considerations other than propagation mechanisms and system design, and (2) any diversity arrangement can be used with good effect.

4.4.25 Combiners

4.4.25.1 The second area where design approaches for a diversity system are in some dispute is in the choise of combining techniques. So far we have discussed a simple switch combiner whose output is merely the better of the two input signals. However, there are adder combiners, ratio combiners, and others which make more efficient use of the two signals, and can improve performance substantially if adjusted correctly.

4.4.25.2 Combiners can also be classified in accordance with the point in the system where combining takes place. The examples in figures 4.4-25 and 4.4-26 imply combining only after both signals have passed through complete receivers, have been detected, and brought down to baseband. This is called postdetection combining, and is widely used as a simple and very reliable method. But the signals may also be combined at the IF output or at RF in the waveguides ahead of the receiver. Such methods are called predetection combining. In principle, the earlier the signals are combined the better is the ultimate performance. Another advantage of the predetection combiner is that if a relay point is simply a repeater, detection is unnecessary and may be eliminated. The principal difficulty of predetection combiners is to adjust the phases of the individual signals so that signals always add. In recent years predetection combiners have been much improved.

4.4.25.3 Except for frequency diversity signals, which cannot be combined at RF, the combining technique is independent of the type of diversity used.

4.4.25.4 See paragraph 4.5.34.3 and 4.5.34.4 for a discussion of problems with combiners for digital systems.

4.4.26 Radio Frequency interference and radio noise

4.4.26.1 Interference from external sources should be considered in the link design to insure that noise contributions from such sources and also from sources within the system will remain well below tolerable levels. Co-channel and adjacent channel interference from other links in the system will be discussed in Section 4.5. Noise associated with modulation, demodulation, and the linearity or delay in electronic modules is considered under the topic equipment intermodulation noise (sec. 4.5.20). In this and the following section noise types and sources external to the system are identified and site modification and equipment techniques which can be used to minimize interference are discussed. Interference considerations applicable to route selection were treated in Section 4.2.33.

4.4.26.2 The operating threshold of a radio receiving system is determined by (1) the level at the receiving antenna terminals of the available powers of the additive unwanted radio signals and additive radio noise with which the wanted radio signal power must compete, (2) the fading of the wanted radio signals, (3) the fading of the unwanted additive radio signals, and (4) the fading of the additive radio noise. The operating noise threshold of a radio receiving system is the operating threshold in the absence of any additive unwanted signals.

4.4.26.3 Radio noise may be classified in terms of its source. The following is a typical list of sources:

a. Natural additive radio noise sources
   (1) Galactic noise
   (2) Solar noise when antenna points at the sun
   (3) Sky noise

b. Man-made additive radio noise sources
   (1) Power lines or power supplies
   (2) Automotive ignition systems
   (3) Fluorescent lights
   (4) Switching transients
   (5) Electric razors
   (6) Door bell buzzers
   (7) Electric motors

4.4.26.4 Radio noise from these sources has a spectral energy distribution that varies more or less uniformly over wide bandwidths throughout the radio frequency spectrum. Figure 4.4-27 indicates typical noise levels and receiver threshold levels over the frequency range 1 to 100 GHz in terms of the median operating noise factor F_{am} in dB above the kT_0b watts of thermal noise in a bandwidth b Hz at a reference temperature chosen at $T_0 = 288.4°$ K SO that

$$10 \log (kT_0b) = 10 \log b - 204 \text{ dBW}. \qquad (4.4\text{-}17)$$

4.4.26.5 Atmospheric noise at the median level is insignificant at frequencies above 30 MHz. Only occasional local thunderstorms which occur approximately 2% of the time create a great deal of interference throughout the VHF and UHF bands (up to 3000 MHz).

4.4.26.6 The galactic noise curve after a ±2 dB allowance for temporal variations indicates the upper limit for this source. However in any given situation the galactic noise levels should be calculated considering critical frequencies and any directional properties of the antenna. When antennas with very narrow beams are directed at the galactic center, it appears to be about 10 dB "hotter" than the median background noise. Solar noise must also be considered when using highly directional antennas. As an example, when antennas with beamwidths of 0.5 degrees or less are pointed at the solar disc, the quiet sun is expected to produce a value of F = 28 dB at 1 GHz which, however, decreases with increasing frequency at the rate of about 10 dB per decade. The disturbed sun can also cause these quiet sun values to increase by 30 to 50 dB.

4.4.26.7 Sky noise due to absorption by water vapor and oxygen is of importance when low noise-factor receivers are used with narrow beam antenna directed away from the surface of the earth.

4.4.26.8 Man-made noise levels are derived from measurements. The "urban" data include measurements from such locations as the

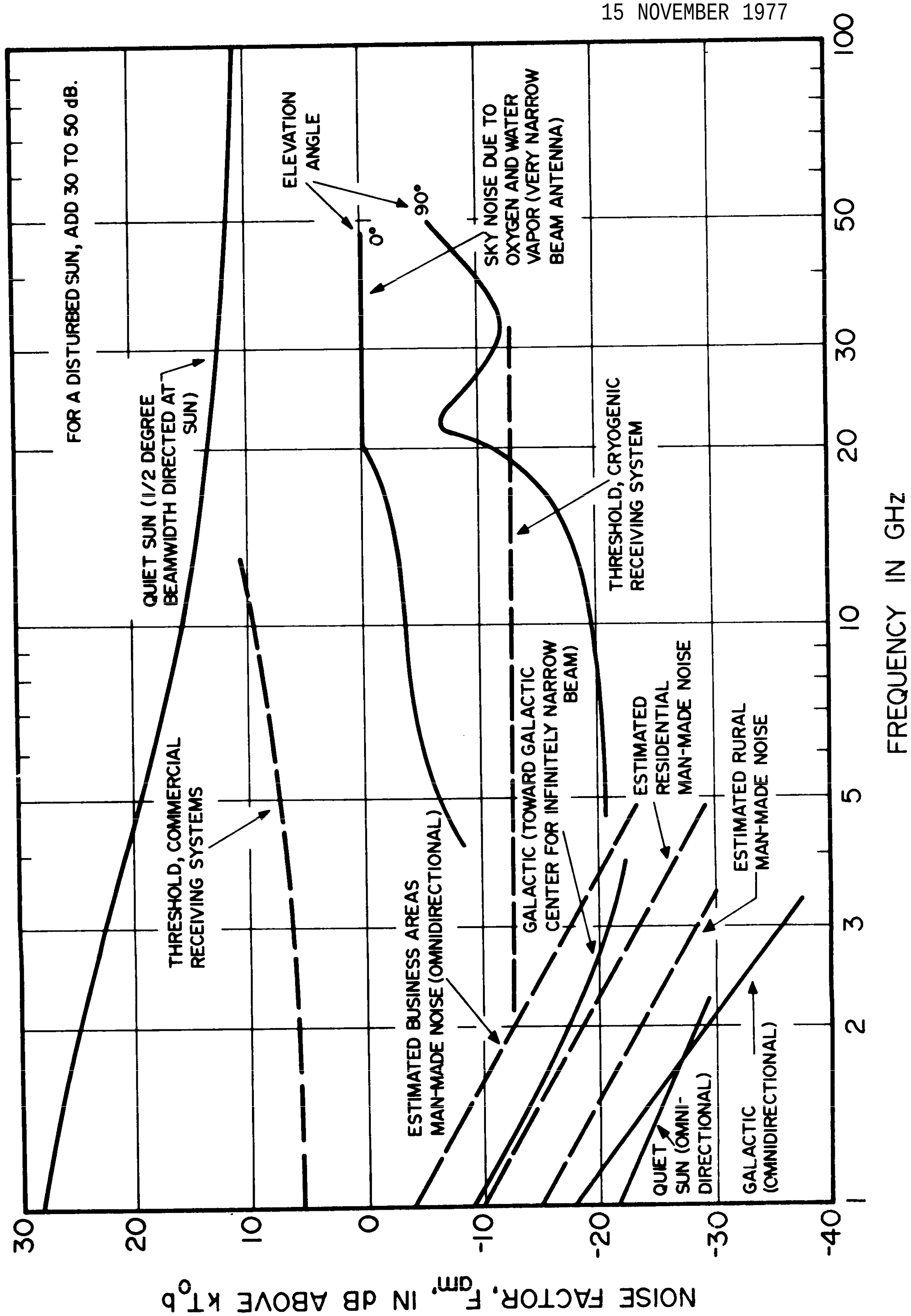


Figure 4.4-27 Typical Operating Noise Factors for Various Radio Noise Sources

business areas of New York, Baltimore, Washington, D. C., Denver, Melbourne, Tel Aviv, Haifa, and Jerusalem. The “suburban” curve was obtained from data taken at Boulder, a location near Washington, D. C., Melbourne, Tel Aviv, Haifa, and some locations in England. The “rural” measurements were made at locations as free as possible from man-made noise.

4.4.26.9 Man-made noise in urban locations can represent the primary limitation to reception at frequencies up to 10 GHz or somewhat higher. A t present there is insufficient knowledge regarding its dependence on angle-of-arrival, polarization, frequency, antenna height, etc., to make adequate determinations of levels likely to be present at the receiving antenna terminals. Statistical descriptions of noise need also to be related to its interference potential relative to the information being received.

4.4.27 Selective interference

4.4.27.1 Undesired signals radiating from transmitters on the same or adjacent frequencies to the one desired are major potential sources of interference. Such sources include satellites, satellite ground stations, radar stations, and other microwave relay systems in the same area. In addition, reflections from aircraft and precipitation act as secondary sources. Since aircraft and precipitation both move with respect to the terminals, they cause selective fading and therefore distort the wanted signal. Above 10 GHz unwanted signals reflected from rain can be especially troublesome because there is a high probability that the wanted signals will be attenuated at the same time the undesired signal is reflected into the receiving antenna. Quantitative information for estimating the outages due to these various sources will often be impractical to obtain but the following considerations should be kept in mind when designing a particular link:

a. Consider the effect of antenna pattern, gain and polarization on unwanted signal sources.

b. Avoid main beam intersections with undesired sources.

c. Site shielding may be effective when a site must be shared with a source of unwanted signal. Shielding may be accomplished by advantageously locating on the brow of a hill, placing the antenna at a location such that the unwanted source is screened by evergreens, or by actually making a cut in a hill as described in [4], p. 31.

d. Transmission line connections, cable, and component shielding must be designed to prevent radiation leakage. Mechanical RF switches, shutters and probes must be avoided or, where necessary, carefully designed to prevent radiating or picking up unwanted signals.

4.4.28 Equipment considerations

4.4.28.1 This section provides information on available microwave equipment with some of the advantages and limitations of using it in the design of a microwave link. Items are discussed in terms of function, options, flexibility, environmental characteristics, space requirements, susceptibility to interference, gain, dynamic range, bandwidth, reliability, primary power requirements, and any other characteristics which are applicable.

4.4.28.2 Diversity equipment combinations and combiners were discussed in Sections 4.4.22 and 4.4.25, respectively. The equipment which will be considered here are antennas, passive repeaters, RF transmission lines, separating and combining elements, transmitters, receivers, and active repeaters.

4.4.29 Antennas

4.4.29.1 The type of antennas used, and the requirements imposed on them are determined mainly by the frequency range and the operational conditions (density of the networks, required junction stations, extensions planned, etc.). For the various stations, an optimum compromise must be found between efficiency and economy. The essential requirements imposed on the antenna relate to the following characteristics:

a. antenna gain, in the direction of the main beam; in line-of-sight links, antenna gains of over 45 dB should be avoided because of the small half power beamwidth ($< 1^{\circ}$), and the greatly increased requirements for stability and rigidity.

b. half-power beamwidth, which affects requirements for antenna and tower design.

c. attenuation of the side lobes. This is important to prevent interference with other systems working at the same or at adjacent frequencies.

d. reflection factor, which must be kept small, above all in broadband systems (< 5%), to prevent delay distortion of the signal.

The applications of the respective types of antenna are:

a. parabolic antennas are especially economical, combining small weight and small space requirements with low costs. Their side -lobe and back-lobe attenuation is adequate for low- capacity systems, and for single broadband radio-relay links.

b. shell and horn-reflector antennas are more expensive, but offer a more favorable radiation pattern and there - fore are used primarily in broadband systems on links with many parallel radio-frequency channels and at junction stations to prevent mutual interference.

4.4.29.2 Antenna principles - The propagation of radio waves re- quires the use of antennas to launch the electromagnetic wave from the transmission line into the atmosphere, and collect it again at the re- ceiving end. The efficiency with which it does this is called its "gain". Other important parameters of an antenna are its bandwidth, impedance and radiation pattern.

4.4.29.3 Isotropic antenna - The reference to which other antennas are compared is the hypothetical isotropic antenna which, by definition, radiates its energy equally in all directions, so that its "gain" is defined as unity.

4.4.29.4 Gain - Other antennas increase the effective radiated power by concentrating more of this power in a desired direction. Hence, they are called directional antennas, and are characterized by a "gain" with respect to the isotropic antenna.

4.4.29.5 The power radiated from, or received by, an antenna depends on its aperture area.

4.4.29.6 The power gain g of an antenna over the area A relative to an isotropic antenna can be expressed by:

$$g = \frac{4\pi\eta A}{\lambda^2} \qquad (4.4\text{-}18)$$

where

A = actual area in the same units as λ^2.

η = efficiency of antenna aperture (usually 55%).

λ = wavelength at the operating frequency.

4.4.29.7 The antenna gain, in decibels is:

$$G = 10 \log g = 10 \log \frac{4\pi\eta A}{\lambda^2}.^* \qquad (4.4\text{-}19)$$

4.4.29.8 Directivity - The directivity, or lobe pattern actually determines antenna gain. An antenna may radiate in any direction, but it usually suffices to know the directivity in the horizontal and vertical planes.

4.4.29.9 Beamwidth - Radiation patterns are often plotted in the form shown in figure 4.4-28. The center of the graph represents the location of the antenna, and field strength is plotted along radial lines, outward from the center. The line at 0° shows the direction of maximum radiation, while in this example at 30°, to either side, the voltage has declined to 0.707 of its maximum value. The decibel ratio of this voltage to the maximum is:

$$20 \log \frac{E_{max}}{E} = 20 \log \frac{1}{0.707} = 3 \text{ dB}. \qquad (4.4\text{-}20)$$

These 3 dB points are considered to be a measure of the antenna directivity; in this case, the antenna has a beamwidth of $\theta_u = 2 \times 30° = 60°$.

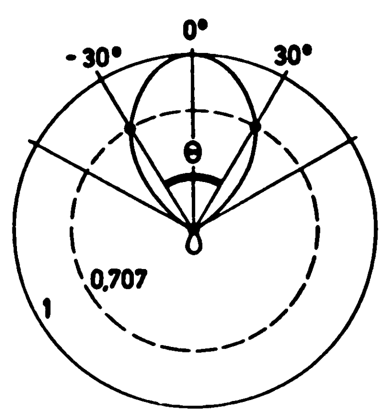


Figure 4.4-28 Typical radiation pattern.

*Unless stated otherwise, all logarithms in this handbook are to the base 10.

4.4.29.10 These diagrams are frequently plotted directly in decibels rather than in terms of field strength. In radio-relay engineering it is also customary to present the patterns in cartesian co-ordinates (abscissa = angle, ordinate = gain). See figure 4.4-31c.

4.4.29.11 Input impedance at the antenna feed point - Each antenna is connected to the transmitter or receiver via a feeder; its input impedante establishes a load on the feeder line as well as on the transmitter or receiver. To have the RF energy produced by the transmitter radiated with minimum loss or the energy picked up by the antenna passed to the receiver with minimum loss, the input or base impedance of the antenna must be matched to the characteristic impedance of the feeder.

4.4.29.12 Mismatch gives rise to reflected waves on the feeder line. They are characterized by voltage maxima V_{max} and minima V_{min} following each other at intervals of one quarter wavelength on the line.

4.4.29.13 The parameter VSWR = V_{max}/V_{min} or the reflection coefficient p, which is the ratio of the amplitude of the reflected wave to that of the incident wave is representative of the quality of the match. They are related by:

$$\rho = \frac{(VSWR) - 1}{(VSWR) + 1} . \qquad (4.4\text{-}21)$$

Another mismatch parameter, which is coming widely into use, is the return loss. which is the decibel difference between the power incident upon a mismatched discontinuity and the power reflected from the discontinuity. See also paragraph 4.5.21.5.

4.4.29.14 In the case of wideband FM radio-relay systems the maximum permissible reflection coefficient ρ ranges from 1% to 5%, in the case of radio-relay connections of low capacity i t mounts to up to 15% and in that of single-channel connections to up to 20%.

4.4.29.15 Relative bandwidth - Matching of the input impedance of the antenna to the characteristic impedance of the feeder is usually possible for a certain fixed frequency. When, however, the antenna is to work within a wide frequency band or, whithout retuning, within a relative large range of carrier frequencies, its electrical parameters must remain uniform within such bands or ranges. The bandwidth of an antenna can be defined as that continuous frequency range over which the desired match can be achieved. The maximum values of VSWR defining bandwidths for LOS systems range from between 1.05 and 1.7 to 1.

4.4.29.16 Front-to-back ratio - Another measure of antenna performance is the ratio of power radiated from the maximum (front lobe) to that radiated from the back lobe of the antenna. This is illustrated in figure 4.4-28, where there is a small lobe extending from the back of the antenna so that in the case of a relay, as an example, some of the energy transmitted can be picked up by an undesired receiving antenna. The ratio is expressed in dB. As an example, if an antenna radiates 10 times the power forward than back, its front-to-back ratio is 10 dB. Parabolic reflector antennas attain front-to-back ratios of 50 to 60 dB while 60 to 70 dB ratios can be achieved by horn reflector antennas.

4.4.29.17 Effective radiated power (e.r.p.) - The effective radiated power of a transmitting system is the product of the power into the antenna and of the power gain of the antenna in watts, or

$$e.r.p. = g_T p_T W \qquad (4.4\text{-}22)$$

where

g_T = power gain of transmitter antenna,

p_T = power into the terminals of the transmitting antenna in watts.

4.4.29.18 It is simpler to express e.r.p. in terms of decibels. Figure 4.4-29 shows a microwave system with a transmitter Power of +40 dBm, or 10 watts. If the antenna gain (in the maximum direction) for this system is 40 dB, the e.r.p. at point B is +80 dBm, or 100,000 watts.

4.4.29.19 If another receiver is located in the direction C, it maybe subject to interference. Because of the directivity of the antenna, the signal leaving at the angle θ from the beam axis toward C is less than that that along the axis at $\theta = 0$. For the example, let the gain toward C be 30 dB less than the maximum gain of 40 dB. Hence, the transmitter antenna radiates in the direction of C with a gain of only 10 dB. The e.r. p. at C will then be 40 + 10 = 50 dBm, or 100 watts.

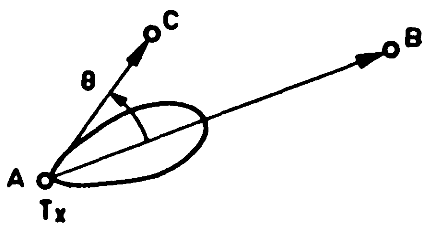


Figure 4.4-29 Illustration of e. r. p.

4.4.29.20 Reciprocity principle - In free space, any two identical antennas may be used for transmitting or receiving interchangeably. In practice, this means that the gain and directivity of an antenna are the same whether it is used for transmitting or receiving.

4.4.29.21 Reflector-type antenna - Antennas for application to radio-relay systems require high gain and good directivity. The desired radiation patterns are obtained by using reflectors (usually parabolic reflectors). The basic function of the reflector is to intercept energy radiated by the feed and reradiate it in the desired direction. In this process some energy is scattered in unwanted directions by irregularities in the reflector surface, lost by transmission through the surface, or diffracted around the reflector edge. Surface irregularities must be small in comparison with the wavelength in order to minimize such losses. In practice, they should be less than one -eighth of a wavelength ($\lambda/8$).

4.4.29.22 The gain of a parabolic antenna is given by:

$$g = \frac{4\pi\eta A}{\lambda^2} = \eta\left(\frac{\pi D}{\lambda}\right)^2 \qquad (4.4\text{-}23)$$

where:

η = aperture efficiency (usually 0.55),

A = true cross-sectional area = $\pi \cdot \frac{D^2}{4}$

D = diameter; λ = wavelength (in the same units).

4.4.29.23 Figure 4.4-30 is a graph of representative parabolic antenna gains in dB above isotropic for various frequencies and diameters. Here, the antenna diameters are given in feet since this conforms to current manufacturers' specifications.

4.4.29.24 The operation of a parabolic reflector is illustrated in figure 4.4-31a. The feed point is located at the focus F of the parabola. The drawing represents a cross-section through a paraboloid of revolution. For large circular apertures (i. e., those whose diameter is large compared to the wavelength) with uniform illumination, the beamwidth between first null points (see figure 4. 4-31c) is

$$\theta_n = \left(\frac{123}{\sqrt{\eta D_\lambda}}\right)^{o} \qquad (4.4\text{-}24)$$

where D_λ is the diameter in multiples of the wavelengths. Similarly, the beamwidth between half-power (3 dB) points is

$$\theta_u = \left(\frac{51}{\sqrt{\eta D_\lambda}}\right)^{o}. \qquad (4.4\text{-}25)$$

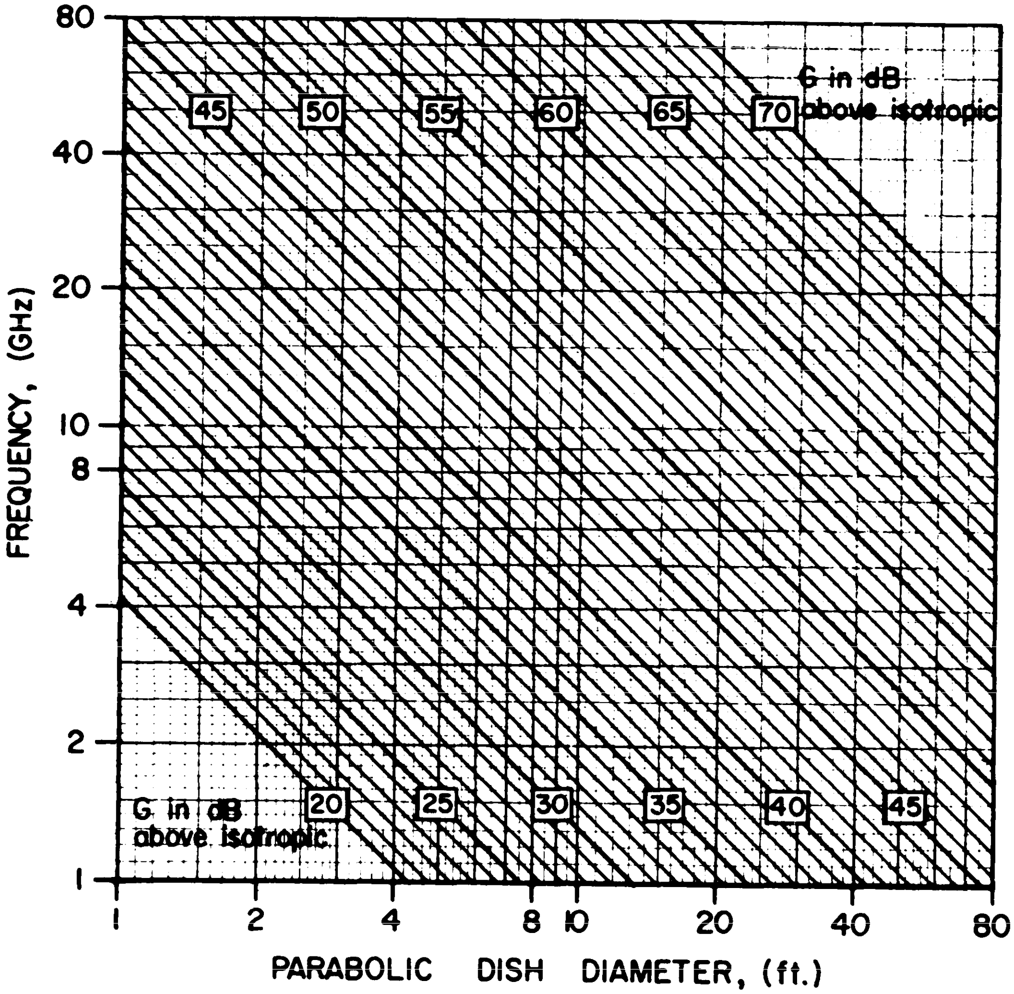


Figure 4.4-30 Parabolic Antenna Gain, G

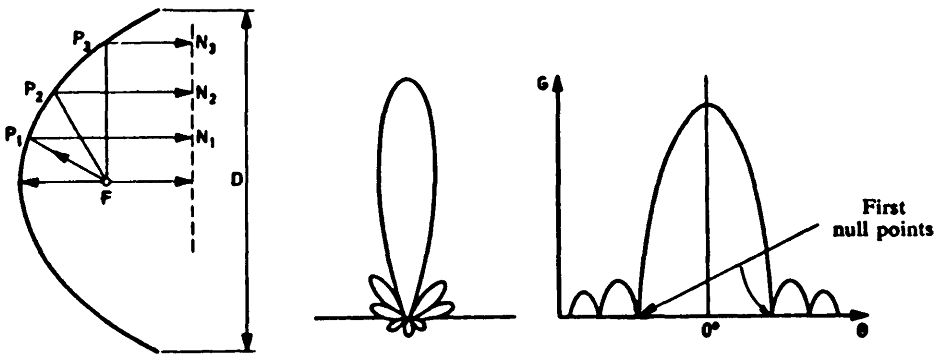


Figure 4.4-31 Directivity of parabolic antennas

4.4.29.25 Figure 4.4-32 is a graph of circular parabolic antenna beamwidth versus antenna gain. Because of power fading due to variations in angle-of-arrival, it is unwise to specify antennas with vertical beamwidths less than 0.5° (section 4.4.13). Because of feed horn aperture blockage, there is also a minimum size of parabolic antenna that is normally manufactured at any given frequency. Figure 4.4-33 is a graph of recommended maximum vertical aperture widths for use on LOS relay links.

4.4.29.26 In practice, the paraboloid is never illuminated uniformly, but the illumination tapers off towards the outer edge so that the overall gain is reduced. This taper is reflected in the formulas by the factor η. The taper also acts to decrease the sidelobes, thereby improving front-to-back ratio and reducing potential interference.

4.4.29.27 Dipole elements are sometimes used as radiators from about 300 MHz to approximately 3 GHz, with resulting antenna gains of 30 dB or more, but waveguide horn feeds are more commonly used.

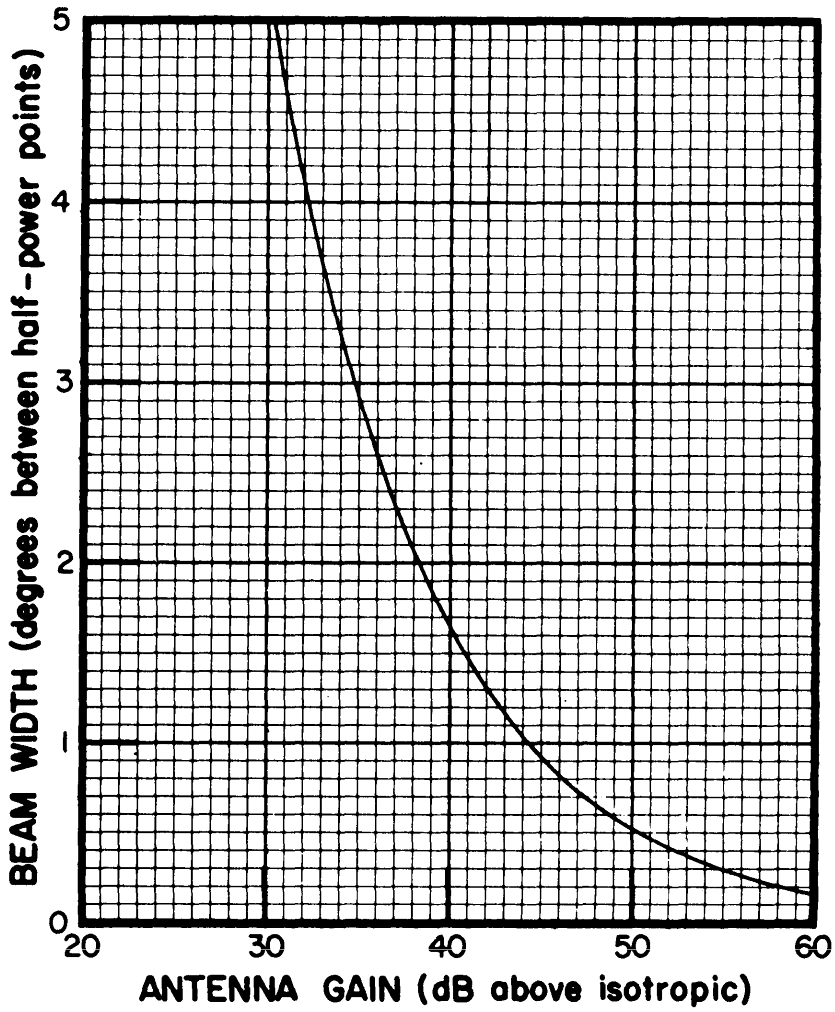


Figure 4.4-32 Nominal Antenna Beam Width as a Function of Gain

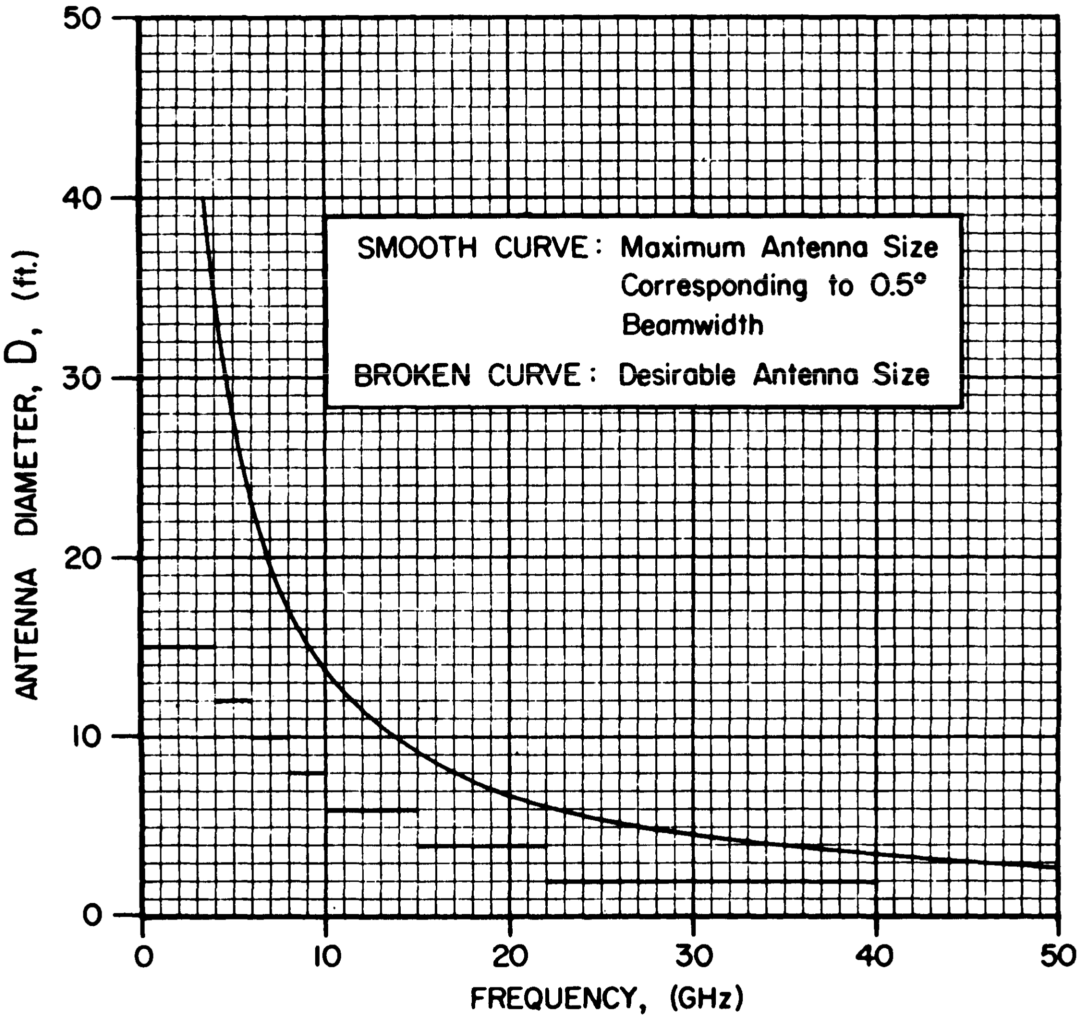
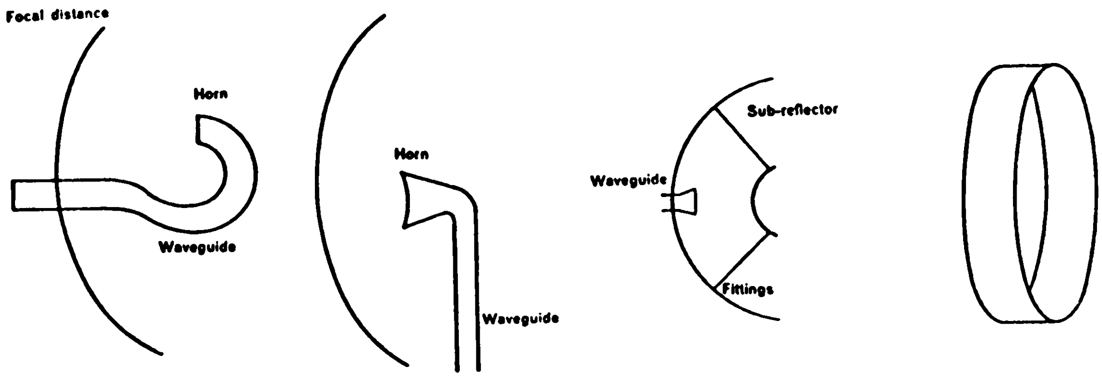


Figure 4.4-33 Recommended Vertical Antenna Aperture Dimension for Line-of-Sight Systems

4.4.29.28 Four types of improved parabolic antennas are illustrated in figure 4.4-34. In (a), two types of feed horns are shown, the "button-hook" feed and the front-feed type. These antennas provide only one polarization when a rectangular waveguide feed is used, and both horizontal and vertical polarization with a square waveguide feed. Bandwidth is usually sufficient to cover several hundred MHz; e. g., from 3500 to 4200 MHz, with a gain of about 40 dB for a 3 meter dish. New types of antenna provide dual operation in two widely separated frequency bands simultaneously; e. g., in the 6 and 11 GHz bands, with both horizontal and vertical polarization. This necessitates the use of two feeds for each antenna.

4.4.29.29 The "Cassegrain" type of antenna shown in (b) uses a subreflector at the focal point to illuminate the parabola. The sub-reflector is itself illuminated from the waveguide feed, which is circular or square in cross-section, thereby allowing the use of both polarizations at once. This antenna is used mainly in radio-relay applications from 2 to 10 GHz, with gains equal to those of horn-fed types. It has also been used in satellite earth-stations, in sizes up to 30 meters for both the 4 and the 6 GHz frequency bands.

4.4.29.30 The shield, shown in (c) is used to suppress side and back lobes in parabolic antennas of both horn-fed and Cassegrain types, thereby reducing interference and noise. The inside surface of the shield is often lined with absorbing material to prevent reflections.



a. Two types of horn feed

b. Sub-reflector with waveguide feed (Cassegrain type)

c. Antenna shield

Figure 4.4-34 Improved parabolic antennas

4.4.29.31 Horn antennas - Four standard types are shown in figure 4. 4-35; they are often used as feeders for reflector-type antennas. The horn-reflector antenna, figure 4.4-36, has better suppression of side and back lobes and much greater bandwidth than a parabolic antenna with comparable gain. It is fed by a circular or square waveguide, so that both polarizations can be used simultaneously. This permits duplexing of antennas, i. e., the use of one antenna for both transmitting and receiving. One signal uses horizontal polarization while the other uses vertical; the discrimination thus available is sufficient to prevent interference between the two signals. This antenna can also provide dual operation in two frequency bands simultaneously with both horizontal and vertical polarization.

4.4.29.32 Antenna characteristics for special demands of frequency planning - Depending on the frequency range, channel arrangement, application, and the equipment properties, an economic utilization of the frequency spectrum by a suitable selection of the radio-frequencies

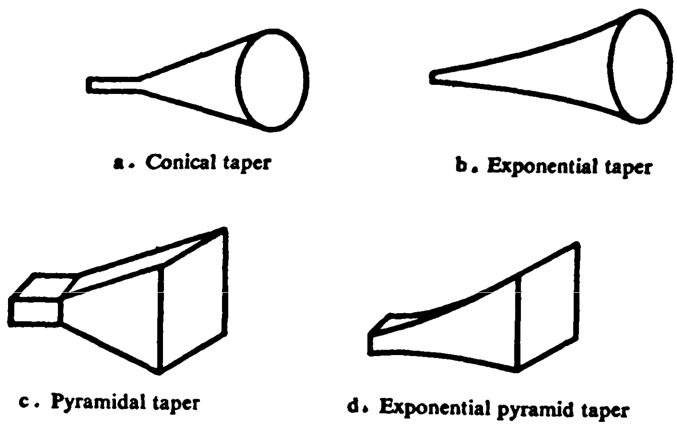


Figure 4.4-35 Types of horn antenna

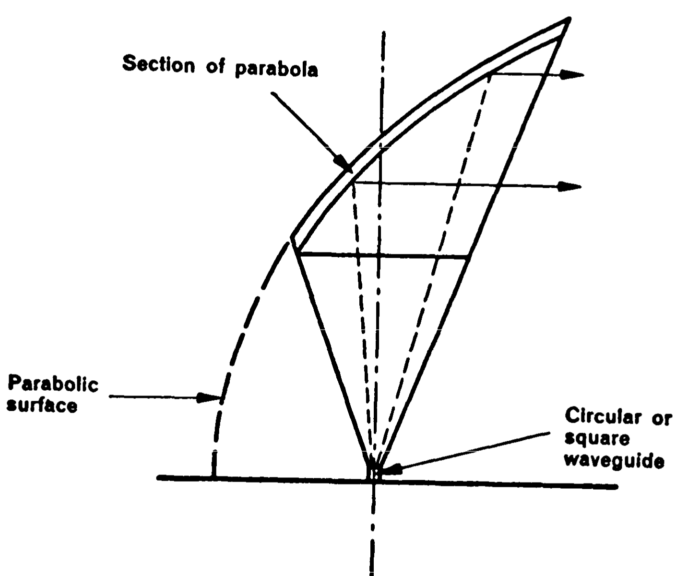


Figure 4.4.-36 Horn-reflector antenna

from the C. C. I.R. recommended channel-patterns calls for certain antenna properties to keep within permissible limits of interference between the radio channels used in the same geographical zone. Co-channel operation, for instances calls for a high front-to-back ratio of the antennas. Adjacent-channel operation on a route usually calls for cross-polarization discrimination (i. e. , use of radiators for two polarizations in simultaneous operation). Adjacent-channel operation at nodal points calls for sufficient sidelobe attenuation at acute angles and, when several antennas of the same type are used in the same location, near-field decoupling must be adequate.

4.4.30 Mechanical stability of antennas

4.4.30.1 In order to obtain the reliability required for the communication system, the structure supporting the antenna must have a long term mechanical stability compatible with the beam characteristics of the microwave antenna. The structures involved in maintaining this mechanical stability are the antenna mount and the tower. The strength and cost of mounts and towers needed for supplying the required resistance to deformation will depend upon the wind velocities and ice loading conditions characteristic to the area where the antennas are being installed. The requirement for vertical angular stability is somewhat more stringent than for horizontal stability since the beam vertical angle of arrival may be shifted by changes in the refractivity structure of the atmosphere as well as by mechanical deformations.

4.4. 30.2 Two possible types of unwanted mechanical displacements of the antennas are elastic displacements (such as a torsional vibration and sway), and inelastic displacements due to back lash in antenna mounts, slipping of antenna mount clamps, changes in guy wire stress, foundation settling, or bending of structural members. The limit of elastic change in horizontal antenna orientation for an antenna mounted at the top of the tower should be less than ±0. 2° during 99% of the time. The estimate of wind loading forces should be based on the time distribution of estimated wind velocities for the geographic area in which the antennas will be mounted and the antenna aperture area for a 0. 5° beamwidth which should be based on antenna diameters taken from figure 4.4-33.

4.4.30.3 The limit of horizontal inelastic movement of the tower and the antenna mount should be such that the horizontal change of antenna orientation will not exceed ±0.1° during its operational life. This much change in orientation may be allowable only from an electrical beamwidth point of view since other mechanical considerations may necessitate an even tighter tolerance.

4.4. 30.4 The tower and mount should be stiff enough that wind and ice loading do not change the vertical orientation of an antenna at the top of the tower either elastically more than ±0. 1° for more than l% of the time, or inelastically more than ±0.1° during the operational life of the tower.

4.4.31 Passive repeaters

4. 4.31.1 Many of the same beam stability considerations that affect the use of an antenna also apply to passive repeaters. The vertical dimension of a passive repeater should not exceed the value of D shown on figure 4.4-33 corresponding to the applicable frequency (see paragraph 4.4.29.25). For larger reflectors, the horizontal width of a reflector should generally be at least twice the vertical dimension. This stability of the beam is much greater in the horizontal plane than in the vertical plane since changes in atmospheric structure affect the vertical angle of arrival more strongly. An additional reason for this minimum ratio or dimensions

is that the beamidth varies as a function of the projected width of the reflector perpendicular to the path and not of the actual width. The projected width of the reflector is equal to the product of the actual width and cos 0/2 (see figure 4.4-37).

4.4.31.2 For approximate calculations of median path loss, consult the discussion in section 4.2.21. Additional quantitative information on passive repeaters can be foundi n [4].

4.4.32 Gain and radiation patterns of flat reflectors

4.4.32.1 The gain of a flat reflector is [12]:

$$G = 10 \log \frac{4\pi A \cos \chi}{\lambda^2} \qquad (4.4\text{-}26)$$

where A = true area of reflector, in the same units as λ^2

χ = incident angle.

4.4.32.2 A flat reflector is more effective as a passive repeater than a parabolic antenna since the effective area of the latter is less than its true area. Furthermore, parabolic antennas are more expensive and difficult to build than flat reflectors.

4.4.32.3 The radiation pattern of a flat reflector is given by [12]:

$$E = A \frac{\sin[(\pi d/\lambda) \sin \theta]}{(\pi d/\lambda) \sin \theta} \qquad (4.4\text{-}27)$$

where E = secondary field produced by a uniform primary illumination, in the main plane, parallel to side d

d = a side dimension of the reflector, in the same units as λ

θ = angle between beam directions (see figure 4.4-37).

4.4. 32.4 It is important to repeat that the beamwidth of the reflector in the vertical plane can become a limiting factor on the size of reflector just as for active antennas. This happens when the beamwidth in the vertical plane is small enough so that ordinary changes in the angle-of-arrival exceed some fraction of

Too narrow beamwidth also requires stiffer structures to resist deflection under wind and ice loads. However, passive reflectors are not sensitive to polarization differences.

4.4.33 Conditions of Planarity for reflectors

4.4.33.1 Irregularities in the reflector surface result in scattering or defocusing of the energy with consequent losses. The attenuation α in dB, caused by an irregularity of height, p, is [12]:

$$\alpha = 20 \log \cos \left(\frac{p}{\lambda} 360^\circ \right) \text{dB} \qquad (4.4\text{-}28)$$

where p and λ must be in the same units. Normal tolerance holds p to less than $\lambda/8$.

4.4.34 Radio path with single flat reflector

4.4. 34.1 An example of a path with a single flat reflector is illustrated in figure 4.4-37. Here,

d_1 = 33.0 km
d_2 = 1.62 km
f = 11,000 MHz λ= 0.0273 m)
e = 48°.

The terminal antennas are 3 m paraboloids with 63% aperture efficiency so that their effective areas $A_1 = A_3 = 4.45\ m^2$. The dimensions of the flat reflector are 6 m x 3 m, and its effective area A_2 perpendicular to the path is 6 x 3 cos $\theta/2$ = 18 cos 24° = 16.5 m^2. The total loss L is calculated as the sum of the losses for path d_1 and d_2 equivalent to the calculation of free-space transmission loss:

$$L = 10 \log \frac{\lambda^2 d^2{}_1}{A_1 A_2} + 10 \log \frac{\lambda^2 d^2{}_2}{A_2 A_3} \quad \text{(dB)} \qquad (4.4\text{-}29)$$

$$= 10 \log \frac{(\lambda^2 d_1 d_2)^2}{A_1 A_2^2 A_3} = 20 \log \frac{(\lambda^2 d_1 d_2)}{A_1 A_2} \text{ (dB)}$$

$$= 20 \log \frac{(0.0273)^2 \cdot (33.0) \cdot (1.62) \cdot (1000)^2}{(16.5) \cdot (7.05)}$$

$$= 20 \log 542.5 = 54.7 \text{ dB.}$$

4.4.34.2 If we use the same example as above, but with the reflector at mid-path so that $d_1 = d_2 = 17.3$ km, the path loss will increase in the ratio of 20 log $\frac{17.3}{33.0} \cdot \frac{17.3}{1.62} = 14.9$ dB. Hence, the size of the antenna or the reflector, or both, must be increased to overcome the additional loss. Obviously, a reflector near one path terminal is much more efficient. When the loss in either path is less than 6 dB, the reflector is likely to be in the near field of the antenna, and the arrangement becomes a periscope antenna system.

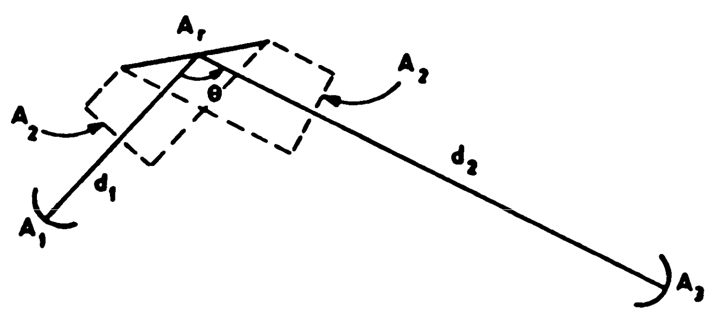


Figure 4.4-37 Path with one flat reflector

4.4.35 Two flat reflectors in one path

4.4.35.1 It is possible to use two flat reflectors in one path, as shown in figure 4.4-38. In this case, where $A_1 = A_4$ (usually), the total loss L can be derived similarly to eq. 4.4-29 and is:

$$L = 10 \log \frac{(\lambda^3 d_1 d_2 d_3)^2}{A_1 A_2 A_3 A_4} \text{ dB.} \qquad (4.4\text{-}30)$$

4.4.35.2 The double reflector system is often used when the angle of transfer becomes less than about 40°, for larger angles the longitudinal dimension of a single reflector becomes excessive. The angles θ_1 and θ_2 should be kept as small as possible in order to reduce the loss.

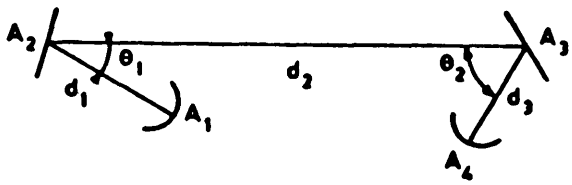


Figure 4.4-38 Two flat reflectors in one path

4.4.36 Two flat reflectors to change beam directions

4.4.36.1 Figure 4.4-39 illustrates a double reflector used to change the direction of a radio beam. The two reflectors are usually made equal in size, so $A_2 = A_3$. Furthermore, in practice, A_1 usually equals A_4. For this arrangement, the total loss L is given by:

$$L = 10 \log \frac{(\lambda^2 d_1 d_2)^2}{A_1 A_2 A_3 A_4} + L_r = 20 \log \frac{\lambda^2 d_1 d_2}{A_1 A_2} + L_r \text{ dB} \qquad (4.4\text{-}31)$$

where L_r = the loss caused by the distance d_r and seldom exceeds 1 dB if the reflectors are in each others near fields.

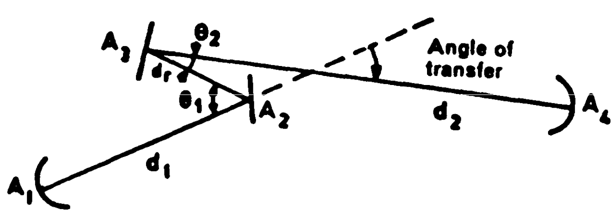


Figure 4.4-39 Double flat reflector

Such a system should be used only in extreme cases since it is expensive and difficult to align.

4.4.37 Parabolic antennas back-to-back

4.4.37.1 Figure 4.4-40 illustrates the use of parabolic antennas back-to-back instead of flat reflectors with a waveguide connecting the antennas. Normal practice in such cases is to have $A_4 = A_4$ and $A_2 = A_3$, so that:

$$= 10 \log \frac{(\lambda^2 d_1 d_2)^2}{A_1 A_2 A_3 A_4} = 20 \log \frac{\lambda^2 d_1 d_2}{A_1 A_2} \text{ (dB).} \qquad (4.4\text{-}32)$$

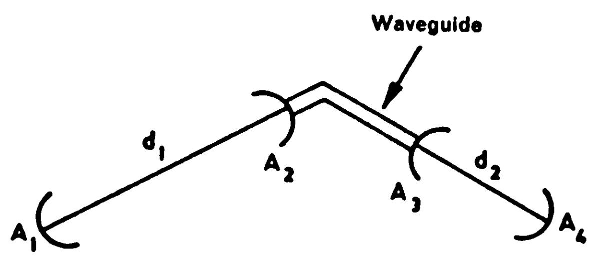


Figure 4.4-40 Parabolic antennas back-to-back

The waveguide loss between A_2 and A_3 must be added to L. Such a system as an alternative to using double flat reflectors has the advantage that correct initial pointing is easier and that it has less tendency to become misaligned. However, it is more expensive.

4.4.38 Periscope antennas

4.4.38.1 Periscope antennas, as illustrated in figure 4.4-41 are used to reduce waveguide losses and expense, but on the other hand they require stiffer towers and have poor discrimination against interference.

The reduced waveguide losses make this system especially attractive between 15 and 40 GHz.

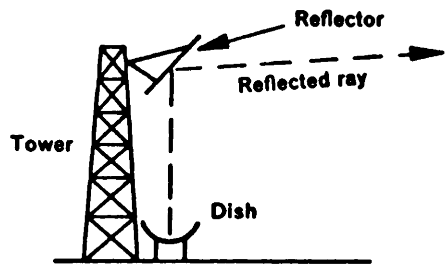


Figure 4.4-41 Periscope antenna

4.4.38.2 The reflector is in the near-field region of the antenna, and its theoretical maximum gain is 6 dB above the gain of the dish. Practical sizes of antenna and reflector limit this figure to 2 tO 3 dB, and the area of the reflector should be more than twice that of the parabolic antenna. The performance also varies with the wavelength and with the distance between the reflector and the antenna.

4.4.39 Diffractors as passive repeaters

4.4. 39.1 Performance on paths with a diffracting mountain obstacle can sometimes be improved by a diffraction grating screen. Such a procedure is especially useful at higher frequencies (11 GHz) where large, truly flat reflectors are expensive and difficult to construct. The diffractor is a microwave version of the optical Fresnel lens, and there are two types -- the screen type and the dielectric type. The screen type acts by blocking off the wave components which would cancel the received field, while the dielectric type shifts their phase to add to the received field. They are placed on the ridge forming the common horizon for a diffraction path, and provide effective gain over the natural obstacle.

4.4. 39.2 Figure 4.4-42 shows the position of the diffractor on the ridge. Since the dielectric type is more efficient than the screen type, it can be made considerably smaller. The diffractor does not need to be on the great circle path between sites.

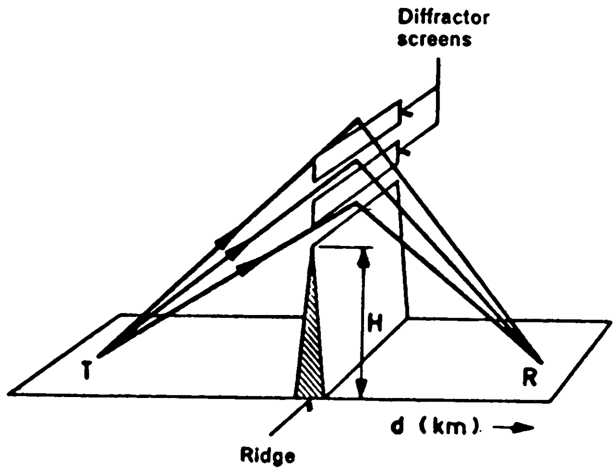


Figure 4.4-42 Microwave diffractor

The gains corresponding to aperture area associated with flat reflectors may be applied to the diffractor or lens type passive repeater.

4.4.40 RF transmission lines

4.4.40.1 There are two general classes of transmission lines which are used for LOS radio links, coaxial cable and waveguide. Other types such as two-wire lines and dielectric waveguide are never used. Coaxial cable and waveguide will be discussed separately.

4.4.41 Coaxial cable

4.4. 41.1 As the state-of-the-art of radio communication has advanced over the past several decades, numerous types of coaxial line have been developed to meet the requirements of system design. The most important of these requirements for LOS radio links are minimum line loss, and ease of installation. The major types of interest are the air-dielectric rigid or flexible lines and foam-dielectric flexible lines. Rigid lines which use dielectric beads to support the center conductor are seldom used above 300 MHz due to the difficulty of installation.

4.4.41.2 At moderate frequencies, say up to 2 or 3 GHz, flexible coaxial cables are used for both transmitter and receiver lines. The available separators for diameters of interest include a helical plastic strip between inner and outer conductors, solid dielectric and foamed plastic dielectrics. These cables are easily installed in continuous runs from the RF equipment to the antennas and are available with factor y-installed fittings. Field installation of fittings should be avoided where at all possible. Most field fittings are mechanical and electrical compromise solutions to a problem which is much more effectively handled in a factory where proper tools and materials and trained craftsmen are available.

4.4.41.3 Pressurization of transmission lines is used except with solid or foam dielectric lines in order to keep moisture out of the line since water between the conductors and corrosion of the conductors will greatly increase line loss.

4.4.41.4 Almost all flexible coaxial cables are covered with a thick sheath of tough plastic which is an important element in the mechanical structure of the line. This sheath may be removed from the line to provide an electrical ground connection but since this weakens the entire structure, it should be avoided. If this is done on bends, it may cause the line to kink where the sheath has been removed.

4.4.41.5 Although coaxial lines are inherently broad-band devices, large diameter lines are unsuitable at high frequencies, since wave-guide modes may be excited which extract power from and interfere with the desired mode. The frequency at which this becomes a problem corresponds to a wavelength in the coaxial line dielectric approximately equal to the average line circumference or

$$\lambda_c \approx 2\pi \frac{r_o + r_i}{2}$$

where λ_c is the wavelength in the medium of interest,
r_o is the inside radius of the outer conductor, and
r_i is the outside radius of the inner conductor.

If the line is operated somewhat below the frequency corresponding to this wavelength, the waveguide modes will be below cut-off frequency and will not be propagated. Operation at or above this frequency can lead to serious problems with waveguide-type propagation in the line.

4.4.42 Waveguide

4.4.42.1 Waveguide transmission lines are commercially available in sizes suitable for frequencies from 300 MHz to 100 GHz. They are superior to coaxial cables in attenuation characteristics at all frequencies and will handle higher power levels. They are mechanically easier to fabricate and sturdier since no center conductor need be continuously supported. However, size and the requirement for precision fabrication may increase the cost over that of coaxial cable for the same service.

4.4.42.2 Several differently shaped cross sections are available in waveguide, with rectangular cross section being the most common; other shapes are elliptical, circular, and square. Generally, square waveguide is used only on antenna feed horns where dual polarized operation is desired.

4.4.42.3 The propagation of energy in a waveguide is different from a transverse electromagnetic wave which will propagate in free space or in a coaxial line. All wave guide modes exhibit a field component in the direction of propagation. If this component, in the direction of propagation is magnetic, the mode is called a TE (transverse electric) mode; if the component in the direction of propagation is electric the mode is called a TM (transverse magnetic) mode. The individual modes are identified by dual subscripts as, for example, a $TE_{2,1}$ mode.

4.4.42.4 In constrast to a coaxial line which can be used for any frequency from dc to that where waveguide modes becomes possible, a wave guide has a low-frequency cutoff below which propagation will not occur in any mode. In a rectangular guide, the wavelength λ_c of the cutt-off frequency is given by

$$\lambda_c = 2a$$

where a is the inside width of the broad wall of the wave guide l

4.4.42.5 For waveguide of elliptical cross-section, the cutoff wave - length depends on the ratio of major-to-minor axes and can be obtained from manufacturers data. For a typical ellipticity of O. 75, it can be said generally that it exceeds the cutoff wavelength of a rectangular waveguide circumscribing the ellipse.

4.4.42.6 At frequencies much above the fundamental cut-off fre- quency other waveguide modes will propagate. It is desirable to have only the fundamental mode present so there is a range of frequencies over which a particular size of waveguide is used. These ranges are specified by the manufacturer.

4.4.42.7 The return loss and VSWR of waveguide lines are strongly influenced by the regularity of the waveguide cross section. For this reason, great care must be taken to prevent deformation of the wave- guide during installation or inspection. This is particularly important where long lengths of semi-flexible elliptical waveguides are used since just one kink or crush will ruin a long expensive piece of wave - guide. For continuous-length waveguides, field fitted connectors should be avoided. It is very difficult to find field personnel who can consistently produce a mechanically and electrically adequate connector installation. If field-fitted connectors are used, great care must be taken and frequent inspections made by a qualified craftsman to insure an adequate job.

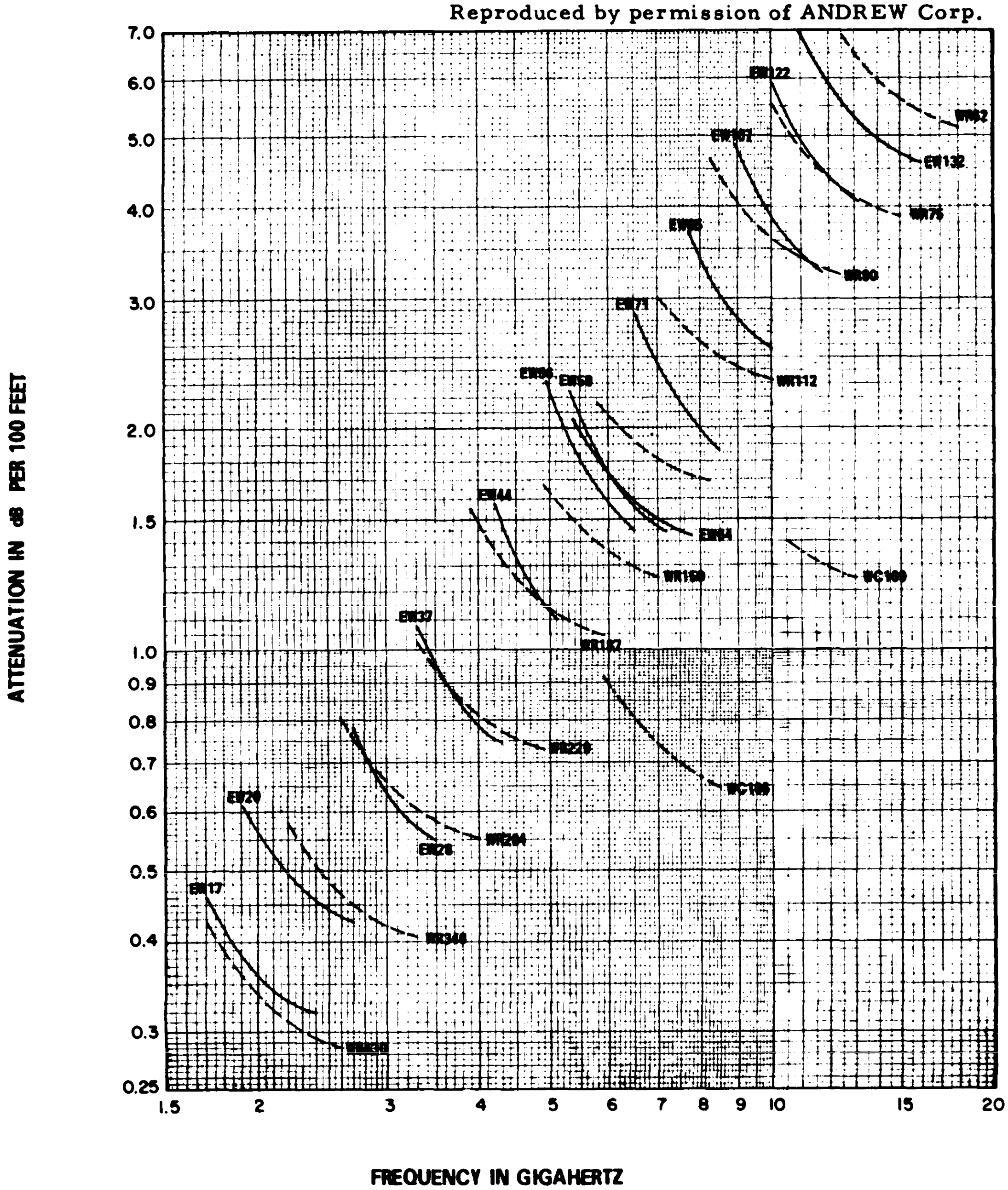
4.4.42.8 In addition to long lengths of semi-flexible elliptical wave-guide or 20 -foot lengths of rigid rectangular guide, other waveguide pieces are necessary. These include 45° and 90° bends in both polarization planes, 45° and 90° twists, short lengths of flexible twistable guide, and wave guide-to-coaxial adapters. Other components made from rigid rectangular guide are available or can be made up. These components are desirable to complete a waveguide installation at the antenna and equipment connections.

4.4.42.9 If an antenna is to be used for both horizontal and vertical polarization, two waveguide runs are generally necessary between antenna and equipment. The signals are combined in a square wave-guide polarization filter which is part of the antenna feed horn assembly. The isolation between signals of orthogonal polarization in such a systerm should be 50 to 60 dB.

4.4.42.10 Figure 4.4-43 shows typical attenuation, and range of single mode use of various waveguide transmission lines.

4.4.43 <u>Microwave separating and combining elements</u>

4.4.43.1 By means of separating/combining networks, groups of several transmitters and several receivers are connected to the same antenna. For determining circulator and/or diplexer network losses, the manufacturer's specifications should be checked. For new equipment, these losses should seldom exceed 1 dB.



Attenuation curves based on:
VSWR 1.0
Ambient Temperature 24° C (75° F)

Conversion Data:
1 dB/100 feet = 3.28 dB/100 meters

Figure 4.4-43 Microwave Waveguide Attenuation

4.4.43.2 The following list of such networks may be incomplete but it contains customary and recommended types for application in radio relay engineering.

a. Circulator Networks (figure 4.4-44). - These are, for instance, three-armed circulators, one arm of which is connected to a filter, while another is connected to a neighboring circulator (or a termination) and a third arm is connected to another neighboring circulator (or the antenna feeder). The interconnection of a circulator and a filter is a separating/ combining filter element.

b. Bridge-type Networks (figures 4.4-45a and 4.4-45b) - These consist of filter networks and four-arm bridge elements such as 3 dB directional couplers or "magic tees". Two bridge elements are connected by two equal filters to produce a separating-filter element. Of the four terminals of a separating-filter element one is connected to the equipment terminal, another to a termination; the two remaining ones are connected to neighboring separating-filter elements or one of the two terminals is connected to the antenna lead or a termination.

c. Branching Networks (figure 4. 4-46). - These networks consist of filters whose inputs or outputs are connected in parallel.

d. Polarization Filters (figure 4. 4-47). - Polarization filters have two terminals for rectangular waveguide going to the transmitters or receivers and one terminal for circular or square waveguide going to the antenna.

4.4.44 Transmitters

4.4.44.1 Figure 4.4-48 is a block diagram of a typical radio relay transmitter. The transmitter for a frequency-modulation system normally comprises of a baseband group, modulator, oscillator, transmit mixer, and radio-frequency amplifier. In direct-modulation

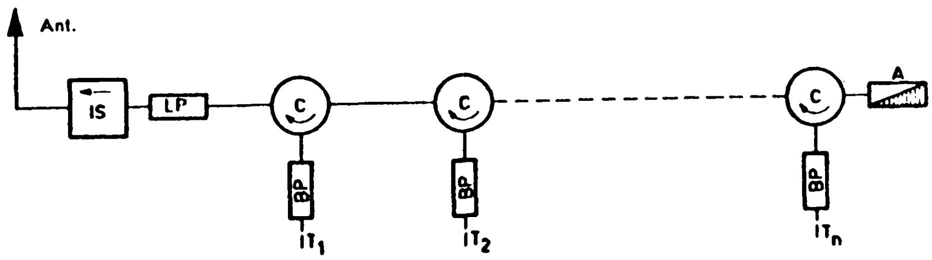


Figure 4.4-44 Circulator Networks

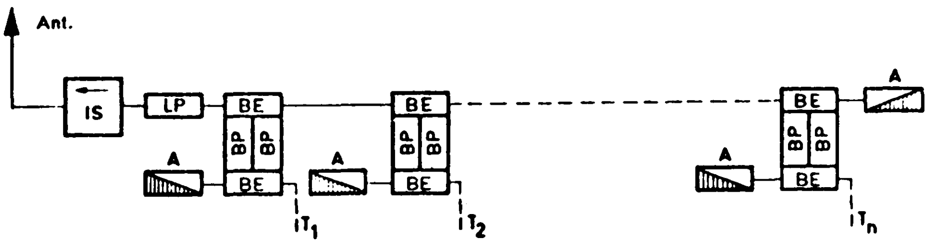


Figure 4.4-45a

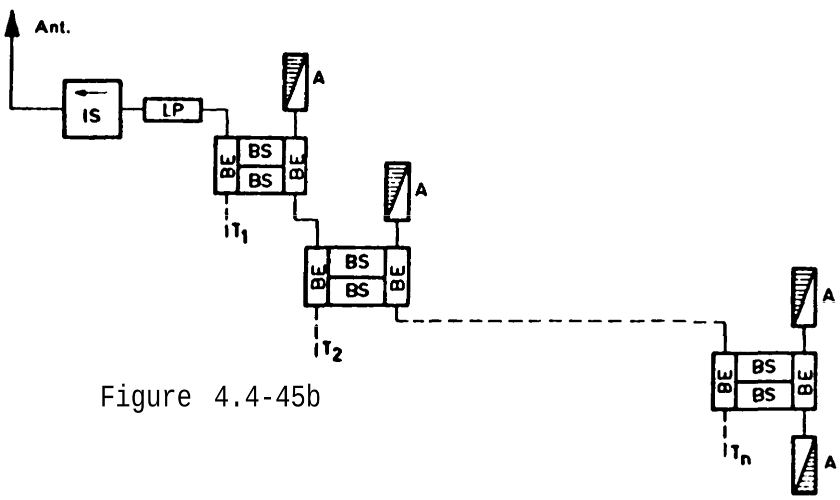


Figure 4.4-45b

Figure 4.4-46 Branching Networks

Figure 4.4-47 Polarization Filters

Ant.= antenna
A = termination
IS = isolator
LP = lowpass filtcr
BP = bandpass filtcr

BS = bandstop filter
C = circulator
BE = bridge element
PF = polarization filter
T_i = equipment terminals

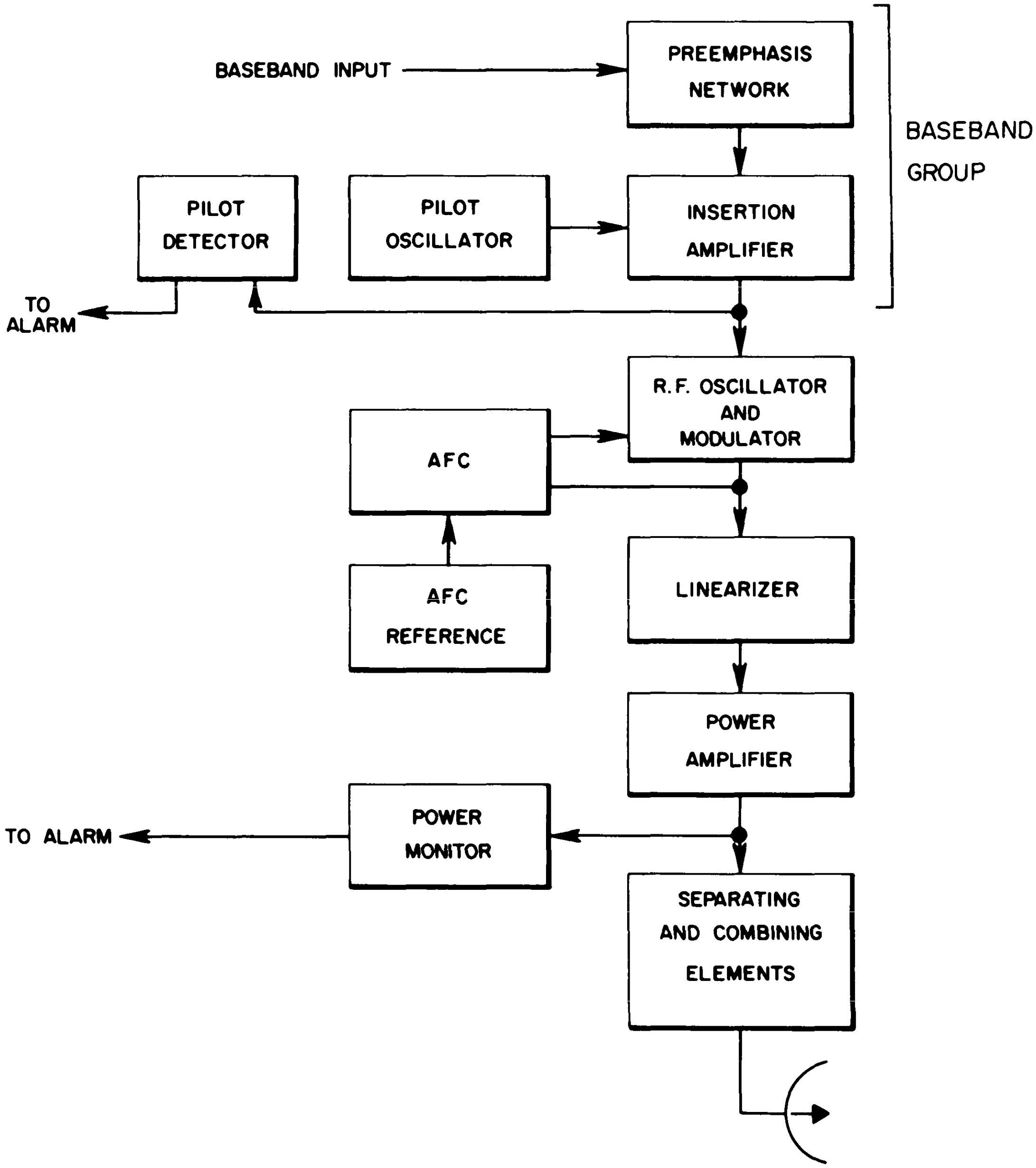


Figure 4.4-48 Block Diagram of Typical Microwave Transmitter

systems, the oscillator which operates at the radio-frequency is directly modulated in frequency, and the transmit mixer is omitted.

4.4.44.2 The Baseband Group includes a pilot oscillator and pilot tone detector for alarm functions, pre-emphasis networks, and an insertion amplifier.

4.4.44.3 Modulation. - The design and efficiency of radio-relay equipment is determined chiefly by the type of modulation used. The various types of modulation eligible for radio-relay systems are essentially:

a. Frequency-modulation,

b. Pulse-modulation (pulse -code modulation).

4.4.44.4 Frequency modulation is most widely used in radio-relay equipment and it is the only type commonly used at present for broadband systems. The following considerations therefore apply to frequency-modulation systems.

4.4.44.5 The generation of microwave frequencies with high accuracy and stability is possible both with free-running oscillators (e. g. , klystrons and solid-state components) or with crystal oscillators and subsequent multiplication. A disadvantage of the free-running microwave oscillators is their comparatively large frequency-drift because of variations in the ambient temperature and in the supply voltages. The frequency therefore must be maintained constant by means of an automatic frequency-control circuit. Either a highly temperature compensated resonator or a harmonic of a crystal-controlled lower frequency is used as a reference for automatic frequency control.

4.4.44.6 When the microwave frequency is produced by multiplying a crystal-controlled oscillation, harmonic mode crystals (mostly around 100 MHz) are customarily used to reduce the number of multiplier stages. Multiplication formerly was made exclusively by means of tubes, but today semi-conductors (variable capacitance diodes, or step-recovery diodes) are used. At the output of the multiplier not only the desired frequency but also other harmonics of the fundamental frequency appear, and these must be suppressed by filters. Moreover, the noise problem needs particular consideration in this case due to spurious responses in some of the diodes.

4.4.44.7 RF transmitter power values required in microwave Systerns range from 100 mW to 15 W, depending on the frequency and on the respective transmission capacity. The RF power may be produced by klystrons, traveling-wave tubes, or solid-state devices. The power stage must be followed by an output filter in order to suppress harmonics and spurious radiations (approximately by 60 dB).

4.4.44.8 The power amplifier is one module which can be changed without affecting the basic design of the transmitter, There are commercially available solid-state power amplifiers with 1 W output up to 15 GHz. In the past, power amplifiers were one of the weakest links in the reliability chain because they required hot-filament devices. Extremely reliable transmitters make it possible to place the RF stages near the antennas on the towers. Thereby the requirements for long RF transmission lines are eliminated and accompanying losses and feeder echo distortion are reduced. Also the requirement for a hot standby transmitter on space diversity systems is alleviated. RF equipment may still have to be placed at the base of towers at sites where modulation and demodulation is required, but if modulators and demodulators are available with improved reliability, all microwave components may be mounted on the tower even in such cases.

4.4.44.9 The development of a transmission device called an injection-locked oscillator which allows the translation of microwave frequencies while retaining the modulation with very little distortion eliminates many microwave components and may supersede the conventional transmitter and much of the receiver at sites where formerly heterodyne repeaters would have been installed. For power levels of 10 W and greater, traveling-wave tube amplifiers will continue to be used for sometime since the reliability of such devices continues to improve.

4.4.44.10 A large variety of arrangements of components and types of components exists and others are being developed. Transmitters for a specific system will probably be selected under one single equipment specification stipulating such overall quality considerations as carrier frequency stability, levels, group delay, linearity, modulator linear deviation range, output carrier-to-noise ratio, and minimum noise power ratio.

4.4.45 Receivers

4.4.45.1 As in the case of transmitters, a large variety of component arrangements and types may be used in a commercial receiver and many others are being developed. A block diagram of a typical microwave receiver is shown in figure 4.4-49. Though not shown in the block diagram of the receiver, sensing and alarm functions are integral to all microwave communications systems.

4.4.45.2 A frequency modulation microwave receiver which, in general, operates on the superheterodyne principle consists essentially of a radio-frequency input filter, mixer, oscillator, intermediate - frequency amplifier, limiter, discriminator, and baseband group.

4.4.45.3 The radio-frequency input filter suppresses unwanted frequencies outside the band to be received (particularly image frequencies), and at the same time prevents unwanted spurious emissions of the oscillator frequency and of mixing products.

4.4.45.4 In the mixer, which is mostly made up of semi-conductor diodes, the arriving radio-frequency signal must be translated into the

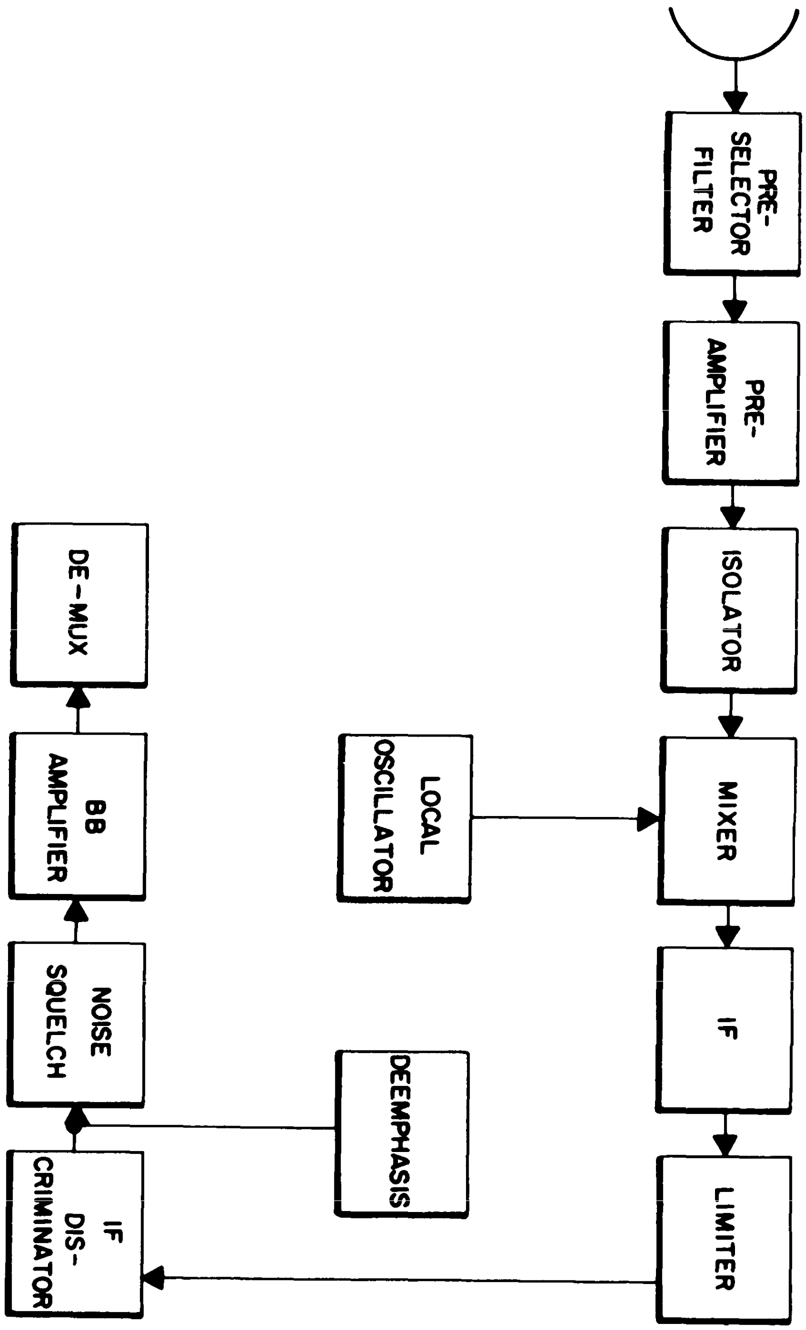


Figure 4.4-49 Block Diagram of Typical Microwave Receiver

intermediate-frequency (IF) band with as little noise as possible being produced. With presently available diode mixers, a receiver noise figure of 8 to 9 dB at 1 GHz and of 10 dB at 7 GHz can be obtained. “ Better noise figures are possible using tunnel-diode amplifiers, parametric amplifiers, and molecular amplifiers; the latter are used however primarily for communication-satellite systems since external noise contributions with terrestrial systems negate the advantages of extremely low internal noise figures.

4.4.45.5 The principles applicable to the transmitting oscillators apply equally to the production of the receiving oscillator frequency.

4.4.45.6 The intermediate-frequency amplifier must have a gain of approximately 70 dB; to compensate for varying path losses it must also have an automatic gain control with a range of at least 40 dB. Since a high freedom from distortion is required, especially in broadband systems, appropriate measures must be taken to provide amplitude and delay equalization.

4.4.45.7 In the subsequent limiter, the synchronous amplitude - modulation superimposed on the frequency-modulated signal must be eliminated as far as possible.

4.4.45.8 The discriminator which demodulates the intermediate-frequency signal must meet high requirements with respect to freedom from distortion, especially in broadband transmission.

4.4.45.9 The receiver baseband group includes a pilot detector, noise limiting circuitry, a baseband amplifier, filters, and demultiplexing equipment.

4.4.45.10 In systems with through-connection at intermediate frequencies, the limiter, discriminator, and baseband circuits are packaged together with the modulator in the modulator equipment housing which is required at terminal stations only.

4.4.45.11 In operation, signal from the antenna passes through a ferrite isolator which reduces intermodulation noise. The signal then passes through a waveguide preselector filter that provides a high IF image injection ratio and eliminates interference from adjacent RF channels. The signal is then mixed with the local oscillator output to produce the 70 MHz IF frequency. The IF output is amplitude limited and the limiter output is applied to a frequency discriminator, a de-emphasis circuit, and a noise muting or squelch circuit that disconnects the baseband amplifier and demultiplexing equipment if system noise increases above a pre-set level. After the squelch circuit, the signal is passed to the baseband amplifier and then to the demultiplexing equipment where the original intelligence is retrieved.

4.4.45.12 Some of the overall receiver equipment specifications which determine its quality are noise figure, local oscillator frequency stability, discriminator linear range, group delay linearity, amplitude linearity, and the minimum noise power ratio it is capable of providing. A preamplifier may be added or removed without changing the basic design of the receiver. If a suitable low-noise preamplifier is placed at the antenna end of a required long transmission line, line loss no longer degrades the carrier-to-noise ratio. Therefore, not only can additional receiver sensitivity be gained but the effects of line loss can be removed. For microwave radio relays low-noise microwave pre-amplifiers are usually the tunnel diode type. These amplifiers become nonlinear at relatively low received carrier levels (-50 to -40 dBm). Because of this gain nonlinearity and the sensitivity of amplifier gain to operating temperature, the following precautions should be taken when using tunnel diode amplifiers:

a. A preselector filter should be placed between the antenna terminal and the preamplifier input so that abnormally high unwanted signal levels can be avoided.

b. Since the gain characteristics of tunnel diode preamplifiers are usually affected by temperature and they are often mounted external to the equipment shelter, a small compartment capable of protecting the preamplifier from weather and having reliable thermostatic temperature control should be supplied.

c. The input to the preamplifier is the location most susceptible to interference.

4.4.45.13 Figure 4.4-50 shows preamplifier noise figures as a function of carrier frequency. These values are based on equipment available at this time. As already noted, noise figures of receivers not using preamplifiers run higher and are typically as follows:

Noise Figure	Frequency Range
10 dB	1 to 10 GHz
12 dB	10 to 36 GHz

4.4.46 Active repeaters

4.4.46.1 An active repeater must be able to perform at least three essential functions. It must (1) provide gain (up to approximately 110 dB), (2) change the direction of microwave route if required, and (3) be able to change the carrier frequency slightly to minimize intra-system interference. (252 MHz is the common frequency shift). There are basically two types of active repeaters, the demodulating type and the non-demodulating type.

4.4.46.2 For an FM/FDM system, a block diagram for a typical demodulating active repeater is shown in figure 4.4-51. Its advantages are mainly flexibility and (at the time of this writing) lower cost. The whole baseband is available allowing channels to be dropped or inserted in an efficient manner. The equipment price advantage occurs as a

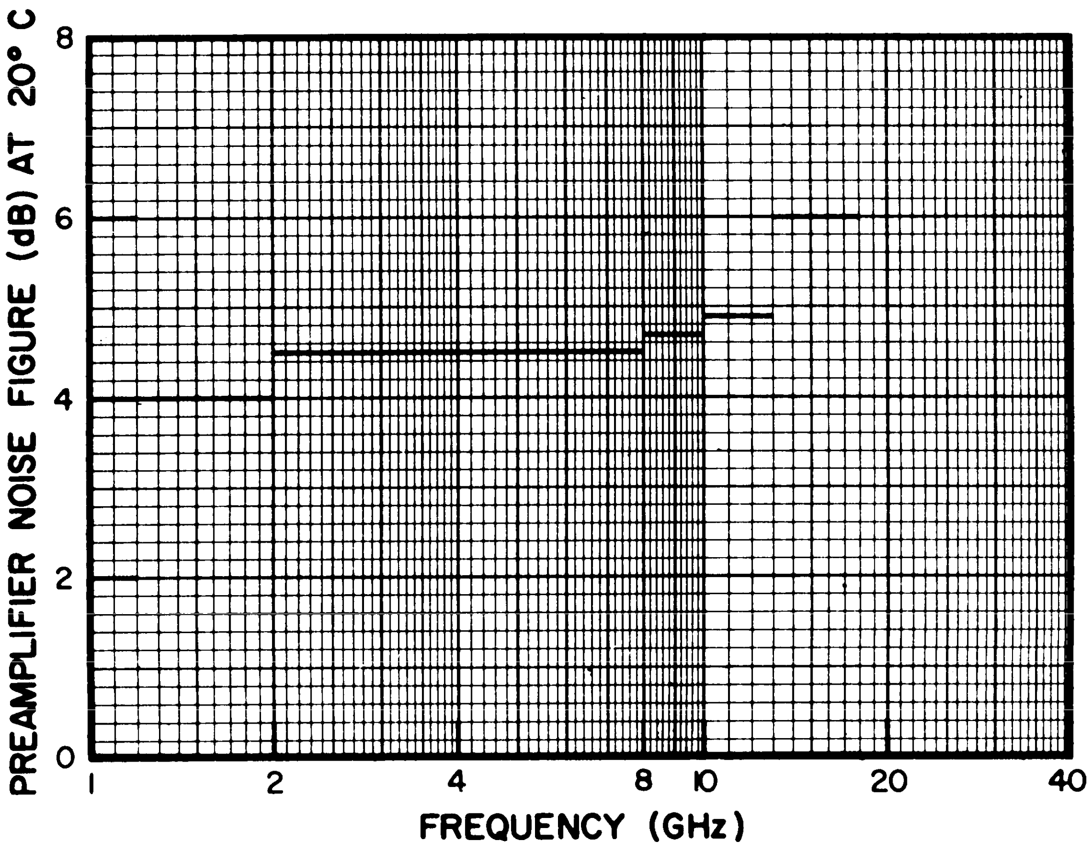


Figure 4.4-50 Nominal Noise Figures for Solid State Receiver Preamplifiers Commercially Available

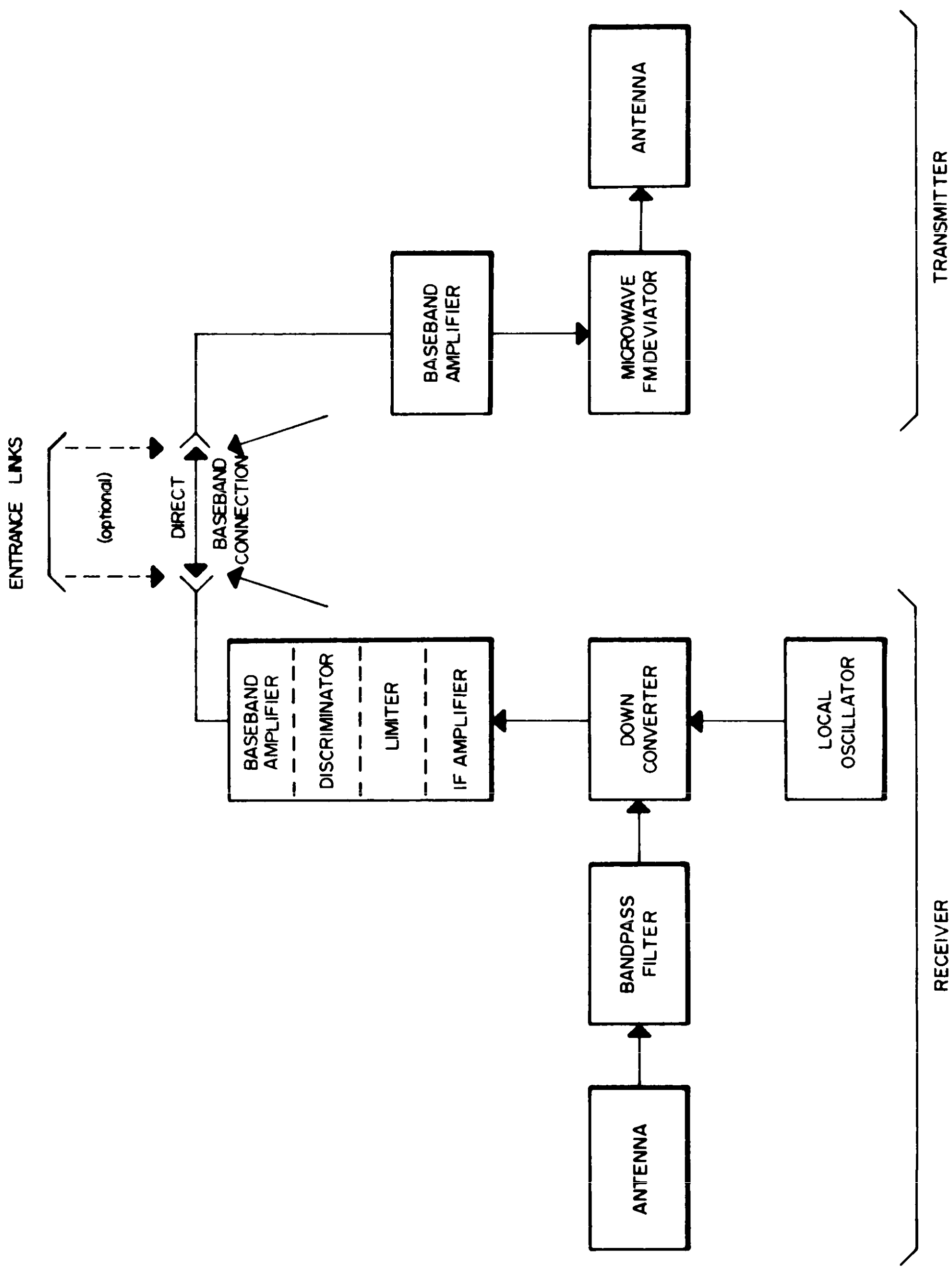


Figure 4.4-51 Baseband Radio Repeater

result of the manner in which gain is achieved; usually all of the repeater gain is obtained at the intermediate frequency and in the modulation - demodulation process. The disadvantages of the demodulating repeater are:

a. It usually introduces more noise per hop than a non-demodulating repeater, but not when pulse code modulation is used and the pulses are regenerated at each repeater site.
b. Baseband levels tend to be less stable because level variations occur primarily in the modulation and demodulation processes. These variations tend to be cumulative in the system.
c. The maintenance of modulator and demodulator linearity is critical for holding intermodulation noise to a minimum. Thus, the cost of maintaining alignment are often larger for the demodulating repeater than for the non-demodulating type.

4.4.46.3 There are basically two types of non-demodulating repeaters - RF and IF types. The RF heterodyne repeater obtains most of its gain by using RF amplifiers, but such a procedure is expensive and for this reason RF heterodyne repeaters are seldom used. RF repeaters using injection-locked oscillators may come into greater usage (see paragraph 4.4.44.9). The IF radio repeater is the most common non-demodulating type, and a block diagram is shown in figure 4.4-52. This repeater type obtains most of its gain at the intermediate frequency which can be done cheaply and reliably with transistor amplifiers.

4.4.46.4 The choice of using through-connecting at repeater stations (through-connection at baseband frequencies or at intermediate-frequencies) is determined by technical possibilities (orderwire or

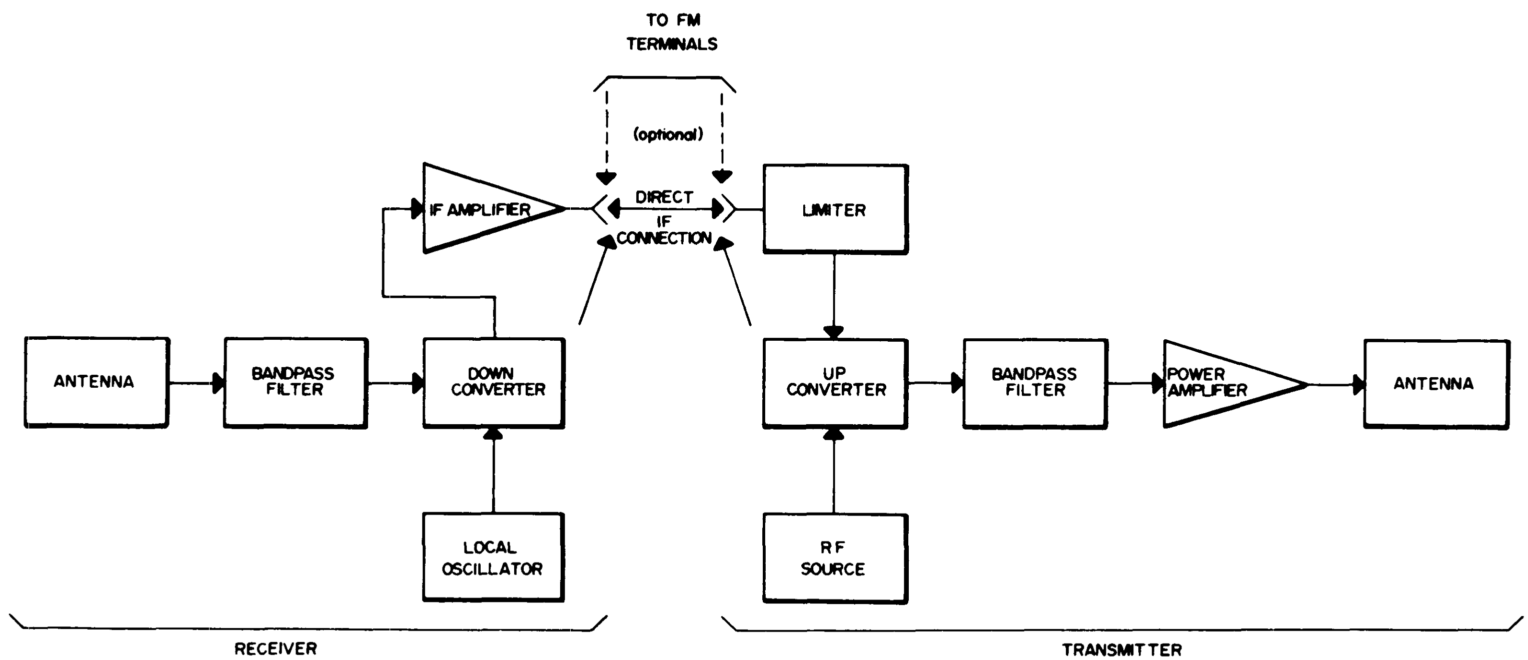


Figure 4.4-52 Intermediate-frequency Radio Repeater

supervisory circuits) and by economic considerations as well as by the traffic demands.

4.4.46.5 In systems using modulation at intermediate frequencies, the baseband signal is converted into a FM standardized IF signal in the modulator. In the RF equipment, this modulated IF is converted into the final RF signal, and raised to the required level. At repeater stations, through-connection can be made in the IF band. Since, in this method, no modulators are used at repeater stations, the system is free from the noise caused by nonlinearities in the demodulation, re-modulation process.

Section 4.5 INTEGRATING LINK DESIGN INTO SYSTEM DESIGN

4.5.1 General

4.5.1.1 Tentative values for various link parameters are calculated or selected using the information in section 4.4. These parameters include antenna heights and separations, antenna types and gains, transmission feeder line types and lengths, transmitter powers, and receiver noise figures.

4.5.1.2 With these tentative values of equipment parameters selected for individual links, they may be integrated into the system design. Several checks and analyses must be completed to properly form the links into a well designed system:

a. The system layout must be brought up to date with current information which involves adding information to system drawings and worksheets (section 4.5. 2).

b. Radio equipment block diagrams with associated equipment requirement lists should be made for each site (section 4.5.3).

c. Frequency compatibility must be assured. A frequency plan must be completed (sections 4.5.4 through 4.5.7) and an analysis of intrasystem interference must be made (sections 4.5.8 through 4.5.13).

d. The tentative values of equipment parameters selected on an individual link basis must be checked and adjusted on the basis of total sys tern performance (sections 4.5.14 through 4.5. 35). System performance predictions are made; on the basis of these predictions. Less reliable portions of the sys tern can be changed to insure adequate overall noise performance to established standards.

e. Finally, the total system design must be checked from the standpoint of overall reliability (sections 4.5.36 through 4.5.40). System reliability cannot generally be predicted accurately, but the system can be examined for weak points.

4.5.2 System layout

4.5.2.1 A system layout with updated path, equipment, and performance parameter summaries should be prepared. This serves as a basis for accurate system analyses and realistic cost estimates. The system layout may simply be a line drawing on an outline map such as the example in figure 4.5 -1. The drawing illustrates the general geometric relationship between the sites and potential intra-system interference problems. Although this figure represents a real system, no attempt is made to analyze it specifically in this handbook.

4.5.2.2 To supplement the layout drawing, three types of summary worksheets are required:

a. a list of antenna locations with site codes, geographical coordinates, and site elevation (worksheet 4. 5-1 a),

b. a list of parameters pertaining to the antennas and their orientation to provide information for understanding the relationship between the terrain configuration and the equipment requirements (worksheet 4.5-1 b), and

c, a summary of parameters for each path to facilitate preparation of system performance predictions (worksheet 4.5-2).

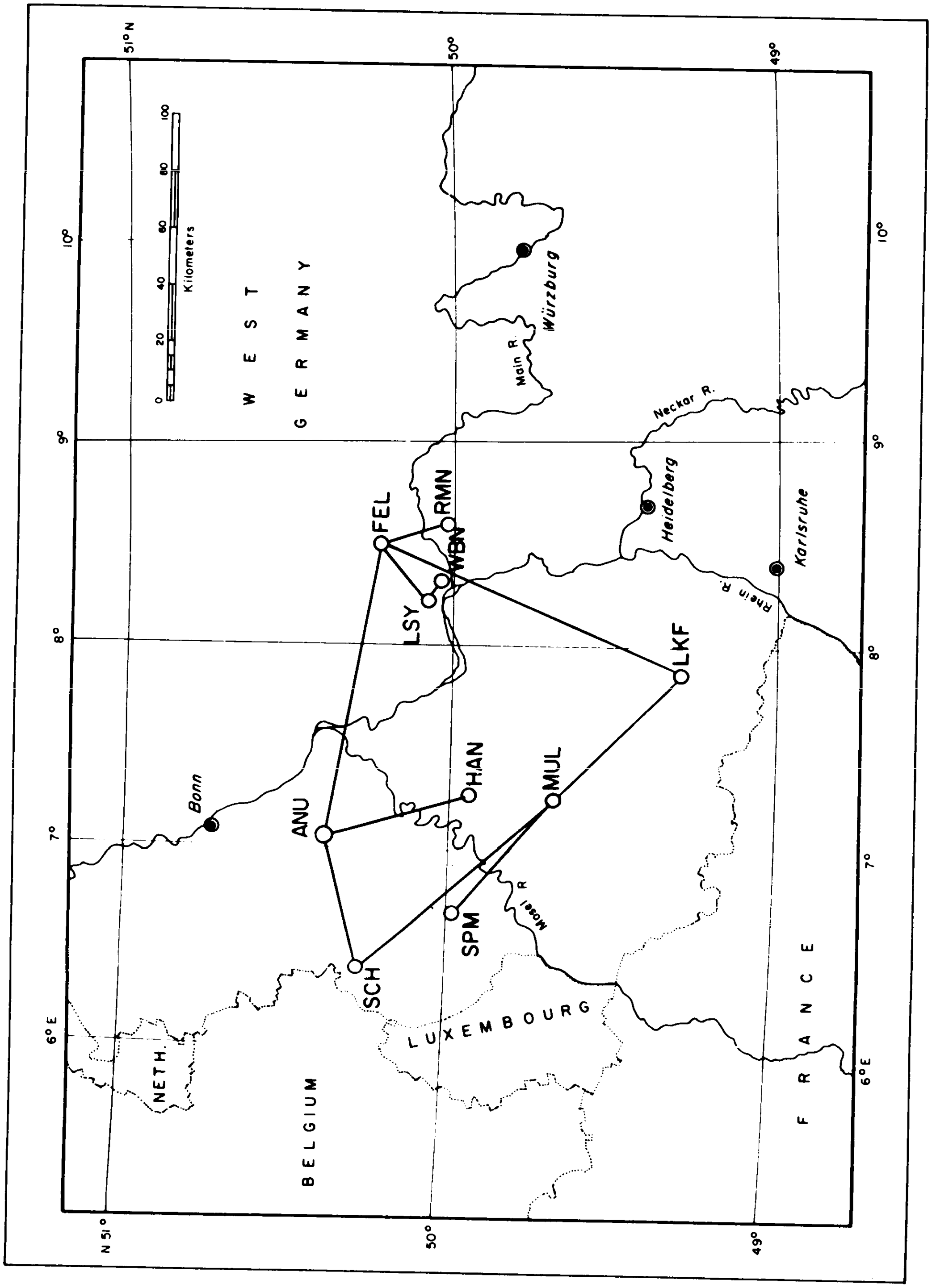


Figure 4.5-1 Typical System Layout Drawing

Site Name & Antenna Designation	Site & Antenna Abbreviation	Latitude	Longitude	Tower Base Elevation above m.s.l. (m)

Worksheet 4.5-1 a Site Location Summary

Worksheet 4.5-1 b Antenna Information Summary

Antenna Ident. No.	Site	Path	Pointing Azimuth from True North	Height above Ground (m)	Frequency (GHz)	Polari-zation (V or H)	Type	Diameter (ft)	Antenna Gain (dBi)	Beamwidth (degrees)	Function (Rx or Tx)

No.	Path	Profile No.	Tower Base Elevation above m. s. l. (m)	Tower Height (m)	Distance (km)	Frequency (GHz)	Free Space Basic Transmission Loss(dB)	Feeder Length (m)	Filter & Feeder Loss (dB)	Total Loss (dB)	Antenna Size (feet)	Passive Reflector Size (ft)	Highest Antenna or Reflector Height above Ground (m)	Antenna Gain, dB above Isotropic	Net Path Loss (dB)	Transmit Power (dBm)	Median Received Carrier Level (dBm)	IF Bandwidth (MHz)	Receiver Noise Figure (dB)	KTBF (dBm)	C/N (dB)		

Worksheet 4.5-2 Path Parameter Summary

4.5.3 Site radio equipment requirements

4.5.3.1 Requirements for equipment at each site should be summarized in block diagrams which for simplicity should show the largest subsystems which adequately define the radio equipment functions at each site. Some subsystems may be broken down into more detailed modules as required. Each block should be given a number, so that it can easily be referred to in detailed breakdowns of equipment requirements. Descriptions of the various types of equipment in the block diagram were given in section 4.4.28 through 4.4.45. Figure 4.5-2 is a typical example of a radio equipment block diagram for a site being used not only as a repeater but also for branching and as a radio terminal. Such a diagram would be much simpler for a site used only as a repeater.

4.5.3.2 Two important uses of the block diagrams are:

a. they insure that each equipment component will be considered individually and that none will be overlooked, and

b. from the equipment lists, a realistic cost estimate can be prepared in the form of lists and tables with comments on each piece of equipment included in the diagram. Some of the information in the comments may concern military specification (if applicable), manufacturers' and model number, cost, acquisition lead time, insertion gain or loss, bandwidth, VSWR, physical size, isolation, etc. The block diagram may also be used to show some subsystem parameters such as RF transmit and receive frequencies, transmitter power, intrasite MUX channel routing, the path designation of the antenna, etc.

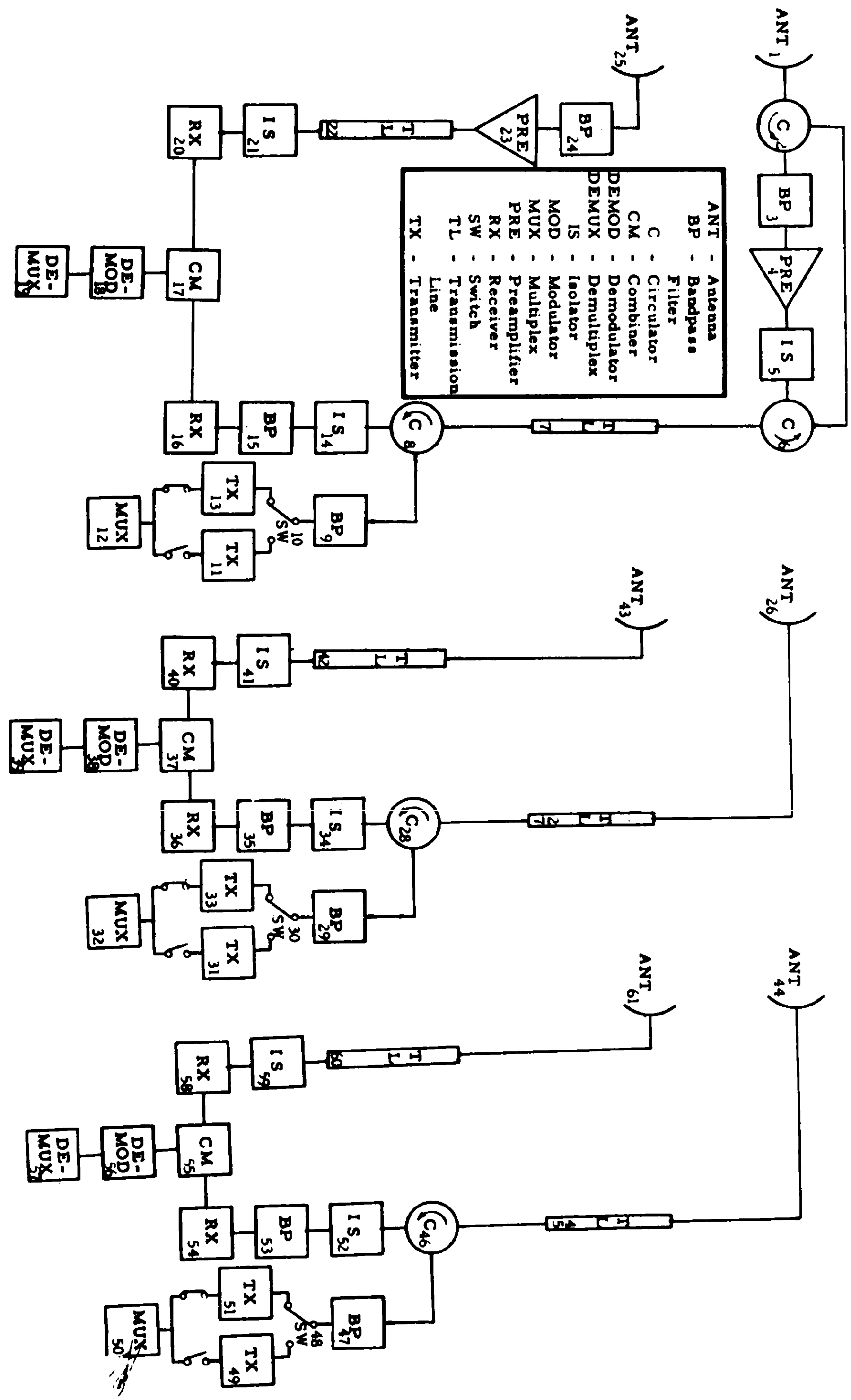


Figure 4.5-2 Site Radio Equipment Block Diagram

4.5.4 Frequency compatibility

4.5.4.1 Adherence to established national and international regulations is essential to achieve interference free operation.

4.5.5 General aspects of frequency allocation

4.5.5.1 Within the frequency bands that are allotted to microwave systems by international conventions, the C.C.I.R. has worked out radio-frequency channel arrangements for the various systems indicating the number, frequencies, and spacing of the RF channels that can be used within the respective bands. Most of these arrangements moreover contain recommendations regarding the number and preferable polarization of the RF channels that may be carried over a common antenna.

4.5.5.2 The provision of radio-frequency channel arrangements is indispensable considering the following objectives:

a. through-connection of microwave systems across national borderlines;
b. prevention of mutual interference between neighboring countries in the border areas;
c. optimum utilization of the available RF spectrum;
d. prevention of mutual interference within countries having great traffic densities.

4.5.6 References to appropriate sections of the Radio Regulations

4.5.6.1 Article 3 of the Radio Regulations [99] provides general rules for the assignment and use of frequencies; Article 4 provides information on the conclusion of special agreements between two or more Members or Associate Members of the I.T.U. regarding the sub-allocation of bands of frequencies, and Article 5 sets out the allocation throughout the world of frequency bands extending from 10 kHz to 40 GHz, 4.5.6.2 Revisions to the Radio Regulations were made at the Extraordinary Administrative Radio Conference in Geneva (1963) and a resolution was drawn up relating to satellite systems and fixed and mobile services in the frequency band 1525 to 1540 MHz. Recommendations relating to the sharing of frequency bands between communication-satellite systems and terrestrial radio-relay systems were also drawn up.

4.5.6.3 Of the recommendations adopted at the Extraordinary Administrative Radio Conference, Geneva, Recommendation 1A relates to the calculation of coordination distance. The C. C. I. R. have subsequently studied further the problems associated with coordination distance and, at the XIth Plenary Assembly at Oslo (1966), approved Report 382 which deals with its determination [8 1].

4.5.7 <u>Choice of one or more frequencies from those available in the radio-frequency channel arrangement</u>

4.5.7.1 Once a frequency band has been chosen, the individual channel frequencies should always be arranged in accordance with C. C. I. R. recommendations shown in table 4.5-1 and figure 4.5-3. The frequency range is subdivided into two parts, the lower half of the band and the upper half. These two halves are separated by a center gap which is larger than, or equal to, the spacing between the center frequencies of two adjacent channels. A frequency pair is designated as f_1, f'_1, or f_2, f'_2, etc.

4.5.7.2 If the frequency spacing of a single pattern (preferred) has been kept sufficiently large in relation to the modulation bandwidth, an additional channel assignment may be made. The latter arrangement is displaced by half the original channel spacing frequency, and may be interleaved with the preferred arrangement. If dual arrangements of this kind are employed, the mutual decoupling requirements must be fulfilled.

Frequency Band, GHz	Recommendation No.	RF Voice Channels	Bandwidth, MHz	Channel Spacing, Δf, MHz	RF Channel Pairs	Center Frequency, f_o, MHz	Channel Center Frequency: Lower Band: f_n, MHz	Channel Center Frequency: Upper Band: f'_n, MHz	Interleave Channels
2 and 4	279-1	300	400	29	6	1,903 or 2,101, 4,003.5	$f_o - 208 + 29n$	$f_o + 5 + 29n$	yes
2	283-1	60 120	200	14	6	1,808, 2,000, 2,203	$f_o - 108.5 + 14n$	$f_o + 10.5 + 14n$	yes
2 and 4	382-1	600 to 1,800	400	29	6	1,903 or 2,101, 4,003.5	$f_o - 208 + 29n$	$f_o + 5 + 29n$	yes
6	383-1	1,800 600	500	29.65 14.825	8 16	6,175	$f_o - 259.45 + 29.65n$ $f_o - 259.45 + 14.825n$	$f_o - 7.41 + 29.65n$ $f_o - 7.41 + 14.825n$	no
6	384-1	2,700 960	680	40 20	8 16	6,770	$f_o - 350 + 40n$ $f_o - 350 + 20n$	$f_o - 10 + 40n$ $f_o - 10 + 20n$	no
7	385	60 120 300	300	7 14	20	7,575	$f_o - 154 + 7n$	$f_o + 7 + 7n$	yes
8	386-1	960 300	300	11.662	12	8,350	$f_o - 151.614 + 11.662n$	$f_o + 11.662n$	yes
11	387	960	1000	40	12	11,200	$f_o - 525 + 40n$	$f_o + 5 + 40n$	yes

Table 4.5-1 C.C.I.R. Radio Frequency Channel Arrangements

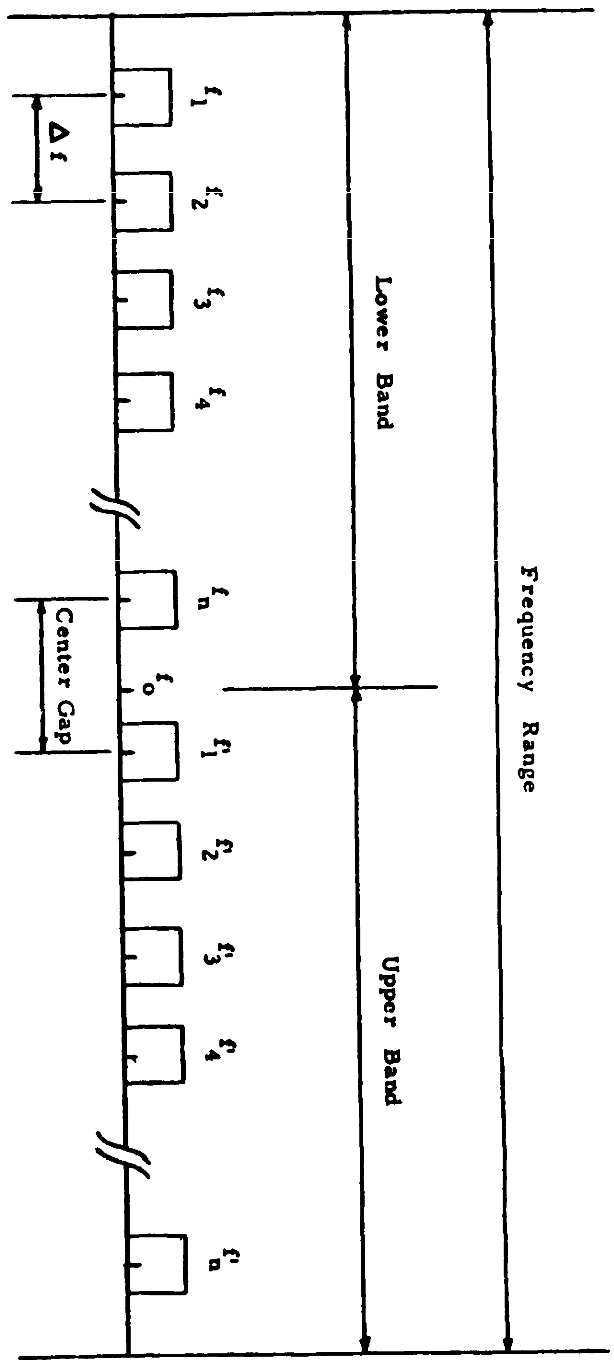


Figure 4.5-3 C.C.I.R. Frequency Channel Arrangement

4.5.7.3 Where two or more radio-frequency channels are to be provided over a route, frequencies should first be assigned either from the odd-numbered group of channels or from the even-numbered group, but not from both since this would require the use of two antennas at each end of each section. As an example, when all the channels from the odd-numbered group have been assigned, further expansion from the even-numbered group would be provided by means of a second antenna with polarization orthogonal to that of the first antenna (see figures 4.5-4 and 4.5-5).

4.5.7.4 Figures 4.5-4, 4.5-5, and 4.5-6 show how a full complement of channels can be arranged. If separate antennas are used to transmit and receive, two will be required at each end of a section, irrespective of the actual number of two-way channels to be provided initially.

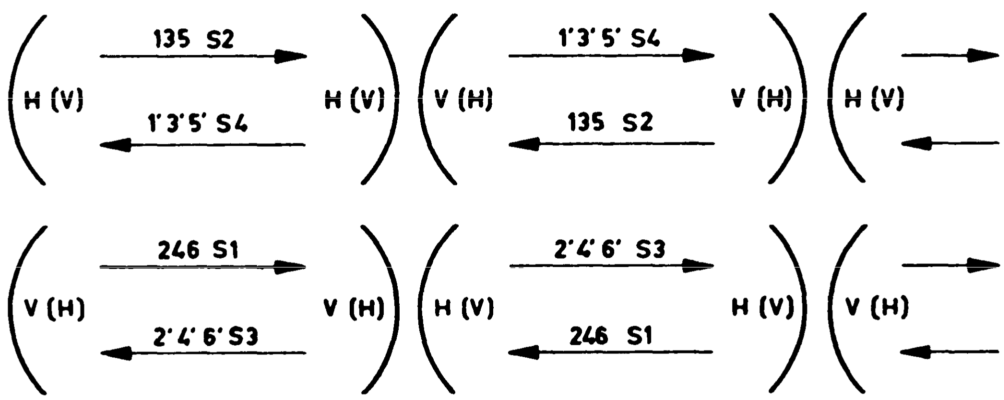
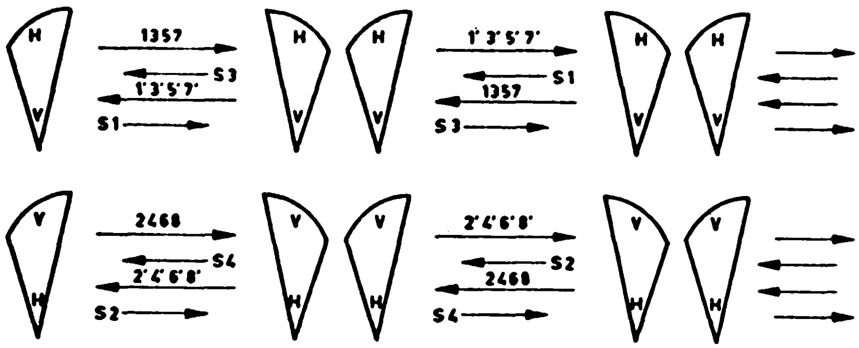
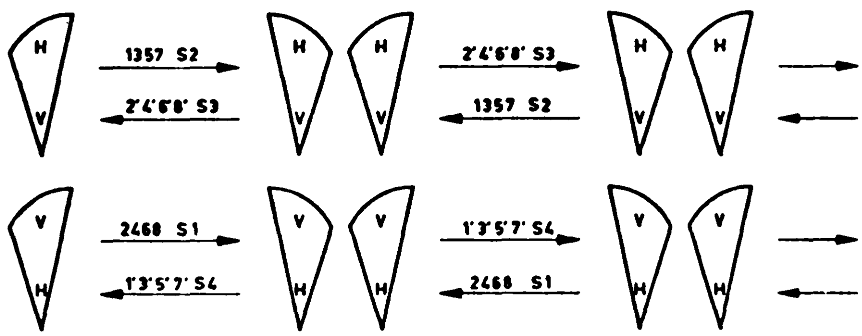


Figure 4.5-4 Single Polarization Antenna Arrangement for the 2 and 4 GHz Bands

Note 1: S 1, 2, 3, and 4 are the CCIR preferred auxiliary channels, in order of frequency.
Note 2: Alternations of polarization in every two hops are available for reduction of overreach interference.



Preferred Arrangement



Alternative Arrangement

Figure 4.5-5 Bipolar Antenna Arrangements for the 6 GHz Band

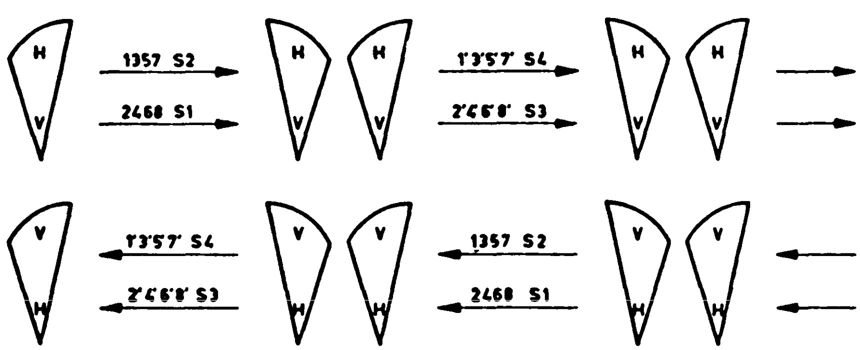
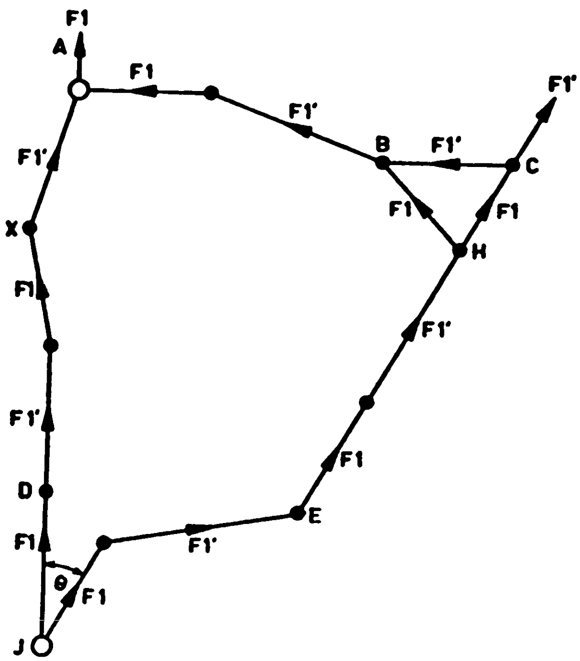


Figure 4.5-6 Separate Transmit/Receive Bipolar Arrangement
for the 6 GHz Band

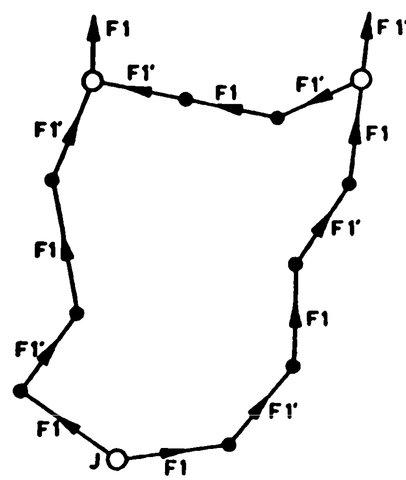
4.5.8 The production and the effects of unwanted couplings

4.5.8.1 In planning a radio system comprising any number of sections in tandem, the initial choice of whether a terminal station shall transmit in the upper half of the frequency band and receive in the lower half, or vice versa, is arbitrary, but once chosen this high/low frequency pattern remains constant for any one station and any one frequency band. When, however, a system is being planned to provide an alternative route between two points which are already connected by a radio-relay system, the high/low frequency pattern of the common terminal station is already determined, and the pattern of the new route must conform to this established pattern if it is to operate in the same frequency band. This can be done by choosing the number of repeater sections in the new route to be either odd or even, depending on whether the number of sections in the original route is odd or even. For example, if the original route contained four repeater sections, the new route may contain two, four or six sections, but not three or five (it is unlikely that fewer than four sections could be used since it is reasonable to assume that the original route used the least number of repeater sections for the distance involved).

4.5.8.2 Figure 4.5-7a shows an example of an unacceptable frequency plan where stations A and B are each receiving signals in the low and high halves of the band simultaneously, and consequently both are required to transmit simultaneously in both halves of the band. The direct path from station H to station B cannot be used and signals between them must be routed via station C. This re-routing action corrects the high/low frequency pattern at both station A and station B, as shown in figure 4.5-7b. Further deficiencies of the arrangement of figure 4.5-7a are evident, namely:



a. Not acceptable because of severe interference, at A and B and small angle θ ; also overreach D-A, E-C and J-X.



b. Acceptable

(Frequencies for only one direction of transmission are shown in order to simplify the diagram; frequency F1 is in the low half of the band; frequency F1' is in the high half of the band.)

Figure 4.5-7 Frequency Assignments for Networks on a Two-Frequency Basis

a. the angle between the two paths at J is too small and co-channel interference would be experienced.

b. overreach signals from D to A, J to X and E to C could occur, giving co-channel interference. The cure would be to stagger the route so that the transmit antennas at D, J and E do not point in the directions of A, X and C.

4.5.8.3 On very lightly loaded routes that are unlikely to expand, i.e., those comprising only one or at the most two hi-directional radio-frequency channels, it may be possible by very careful selection of frequencies to contravene this "rule" concerning the preservation of the high/low frequency pattern. This could save the cost of one repeater station, but if at some later date more channels in the same frequency band were required, it would not be possible to provide them without provision of the repeater station originally saved. To insert an extra station into an existing route cannot be done without considerable difficulty and cost and, inevitably, some dislocation to the traffic on the route.

4.5.9 Types of interference

a. Co-channel Interference (Section 4.5.10)

This term refers to interference from a source, modulated or otherwise, having essentially the same frequency as the wanted carrier within expected stability limits. When the interference is caused by the beat between two relatively high level carrier components having a frequency separation which falls within the baseband of the wanted signal, the predominant interference will be single-tone in character. When the carrier frequency separation falls outside the baseband range of the wanted signal, and when the interference is from a dispersed signal; the character of the interference will resemble that of random noise.

b. Adjacent Channel Interference (Section 4.5.11)

This term refers to interference due to the presence of one or more radio-frequency carriers, modulated or otherwise, immediately adjacent in frequent y to that of the wanted modulated carrier. The term adjacent is normally taken as indicating the adjacent channel in the frequency channeling plan which has been adopted.

c. Direct Adjacent Channel Channel Interference (Section 4.5.12)

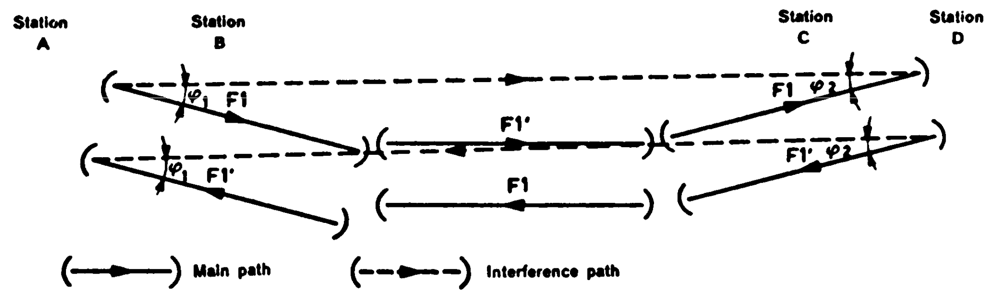
As in case (b) above, this term refers to interference due to the presence of adjacent carriers which may be present when interference due to (b.) above has become negligible. The mechanism of the interference, however, requires the interfering carrier to be modulated.

d. Other Forms of Interference (Section 4.5.13)

This term refers to interference which can arise either from external sources or from unwanted interactions within the radio equipment such as, for example, the image response of the receiver.

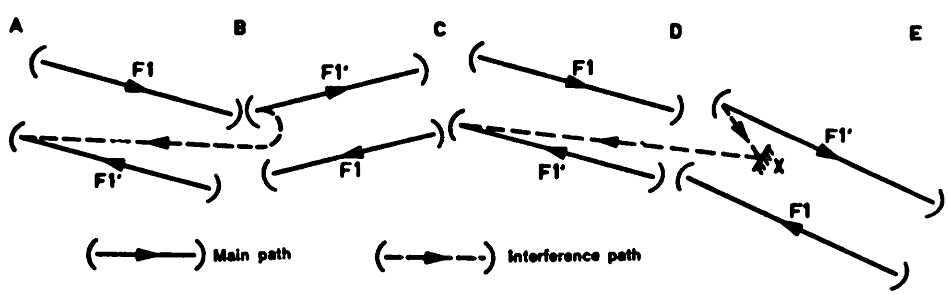
4.5.10 Co-channel interference

4.5.10.1 Co-channel interference arises when there is excessive interaction between signal sources operating on the same, or very close frequencies. It is current practice to transmit a common carrier frequency (Fl) from every alternate repeater station of a radio-relay system. The remaining stations of the system transmit a second carrier frequency (F1') which differs from the first by an amount which depends on the particular frequency plan employed (see
and 4.5-9). This arrangement can result in overreach interference where station A transmitting on frequency F1 illuminates the antenna of station D, and vice versa (see figure 4. 5-8). Protection against such interference is normally provided by careful site selection, and by ensuring that sufficient antenna side-lobe suppression given by the



The ratio (wanted signal/interfering signal) depends on the gain of the antennas at angles ϕ_1 and ϕ_2 relative to the gain in beam and difference of propagation losses between main and overreach Paths l

Figure 4.5-8 Example of Overreach Interference



B. Results from insufficient front-to-back antenna discrimination.
D. Results from a reflection from nearby trees, hill or building, etc., at point X

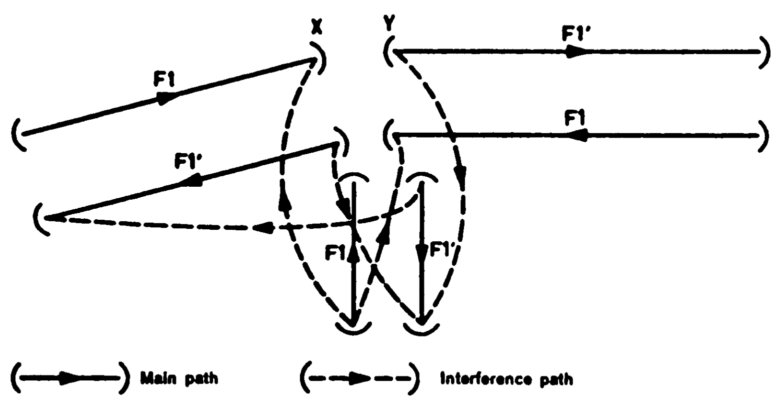
Figure 4.5-9 Example of Adjacent Station Interference angles ϕ_1 and ϕ_2 is provided. In difficult cases it may be possible to provide additional protection by orthogonal polarization of the wanted and unwanted signals. This is not always practicable if, for example, a spur route branches off from one of the stations and it is desirable to provide cross-polar discrimination between the main route and the spur route. Interference may also be reduced by using an interleaved frequency plan over a critical section. In such a plan all carrier frequencies are changed in the same sense by an amount equal to half the adjacent channel frequency spacing. This value is approximately 14.5 MHz in the 2 GHz, 4 GHz and 6 GHz bands when using standard C.C.I.R. recommended frequency plans (see Recommendations 382-2 and 383-1 [81], or 20 MHz when using other C.C.I.R. frequency plans (i.e., for 2700 telephone channels, 11 GHz systems, etc.).

4.5.10.2 Potential advantages of such an arrangement depend on the channel baseband width in relation to the spacing of their carriers, and also on the relative carrier levels. It is generally desirable to use a carrier frequency spacing of not less than three times the highest baseband frequency so that the first-order sidebands of one channel do not overlap the second-order sidebands of the other channel. Closer spacings in terms of multiples of the highest baseband frequency may be used with care, depending on the relative levels of the wanted and unwanted carriers and the degree of interference that is acceptable.

4.5.10.3 A further interference mechanism can be seen in figure 4.5-9 where radiation at frequency F1' from the back of the antenna at station B is received at station A. Even when the front-to-back discrimination of the antenna is sufficient (at least 65 dB) to reduce this interference to an acceptable level, reflections from nearby objects can cause problems as shown at station D (figure 4.5-9). Reduction of this type of interference can be achieved either by antennas of improved directivity (including less radiation from side lobes), by the use of a more suitable site, or possibly by the use of an interleaved frequency plan.

4.5.10.4 Figure 4.5-10 shows an example of interference from a spur or crossing which is similar to that shown in figure 4.5-9 (case D) except that here no reflection need to be involved and the relative gain of side lobes controls the interference level. If, on the main route, signals of the same frequency arriving from opposite directions are of the same polarization, the spur route can be cross-polarized with respect to both directions. If, however, the main route signals are cross-polarized (and there is not necessarily any advantage in this), the spur route should be cross-polarized with respect to the direction with the least angular separation.

4.5.10.5 In some cases it may be possible to reduce the effects of co-channel interference by applying dispersal to the unwanted signal. Dispersal involves phase-deviating the carrier by several radians at a



The ratio (wanted signal/interfering signal) will depend on the front-to-side discrimination of the antennas X and Y.

Figure 4.5-10 Example of Spur Route Interference slow rate and spreads interference over many channels at reduced levels which would otherwise affect a few telephone channels at higher levels. The reduction in interference is most pronounced in the lower frequency channels which are subject to the highest interference levels which are those caused by the beat tone between the wanted and unwanted residual carriers.

4.5.11 Adjacent channel interference

4.5.11.1 Adjacent channel interference can arise when (for a given baseband width and adjacent carrier separation) suppression of the adjacent carrier and overlapping unwanted sidebands is inadequate. The reduction of interference from this source to an acceptable level depends upon several factors. First, adequate separation of the adjacent channel spectra must be provided, and this is taken into account in the radio-frequency channel arrangements recommended by the C.C.I.R. Second, adequate RF and IF selectivity must be provided to reduce the level of unwanted adjacent spectra. In providing such filtering the equipment designer must take into account the possibility of introducing distortion into the wanted signal path. Third, cross-polarized discrimination between adjacent channels should be used to supplement the selectivity provided by filtering. Cross-polarization discrimination of some 25 to 30 dB is both practical and necessary.

4.5.12 Direct adjacent channel interference

4.5.12.1 Direct adjacent channel interference arises when the wanted and unwanted signals are together subjected to amplitude limiting. It is believed that partial conversion to amplitude modulation of the unwanted frequency-modulated signal takes place on the selectivity skirts of the wanted channel. This amplitude modulation is demodulated in the limiter of the wanted channel, demodulates the wanted signal, and appears at the discriminator output along with the wanted signal. The end effect is intelligible crosstalk, and the level of the interference varies by 2 dB for each 1 dB variation in the wanted-to-unwanted carrier ratio. Interference from this source may be reduced to acceptable levels by proper equipment design. Together with the cross-polarization discrimination between adjacent channels, adequate selectivity must be provided prior to limiting.

4.5.13 Other sources of interference

4.5.13.1 Interference can occur within a system as a result of deficiencies in the equipment itself. For example, a superheterodyne receiver has several sensitive regions at which interference can be received, namely:

Sensitive region	Frequency differential between received signal frequency and multiples of the IF
Channel carrier frequency	0; ±1/2 IF
Local oscillator frequency and image frequency	± l IF
	± 2 IF
	± 3 IF

4.5.13.2 Adequate selectivity prior to the low-level mixer is necessary to desensitize the receiver in all regions but that of the channel carrier frequency.

4.5.13.3 The designer must also ensure that the outputs of all local oscillators are of high spectral purity; i.e., as free as possible from spurious signals, random noise and both long-term and short-term frequency changes. Spurious signals in local oscillators can arise from imperfections of the crystal itself, inadequate filtering of undesired crystal harmonics or self-oscillation, and general instability in varactor multiplier chains.

4.5.13.4 A further interference mechanism exists on systems which employ common antennas and feeders to transmit and receive more than one frequency band. All wave guide feeders exhibit amplitude non-linearity to some extent, mainly resulting from imperfections at joints. Such non-linear elements result in intermodulation between the outputs of two or more transmitters, and the resulting unwanted products may fall close to receive frequencies either in the same frequency band or in a different frequency band from that of the originating transmit channels. A careful selection of associated frequencies and quality control of the waveguide joints is required to avoid the worst effects.

4.5.14 Hop/System noise performance estimates.

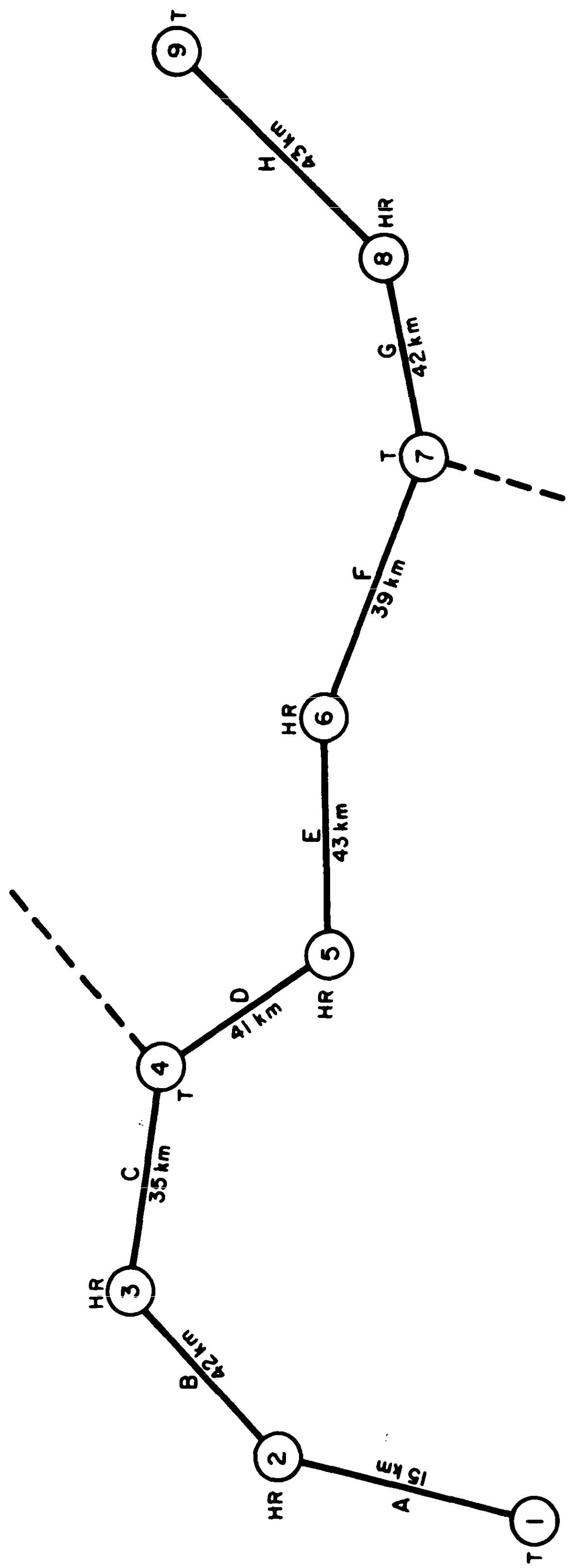
4.5.14.1 Required performance levels are described in the following paragraphs.

4.5.15 DCS noise requirements.

4.5.15.1 Once the link and system lengths are fixed, the total median noise allocation can be calculated. A useful figure is to allow 3 pWO of voice channel noise per kilometer of actual system length; that is, the sum of all individual path length (see [3], p22). This figure is an approachable and probably realizable number. This basic assumptions for noise allocations is that for long systems (say 1,000 to 10,000 km), the total noise will remain within the allowable limits. Some individual hops may have more median noise than allocable and some less.

4.5.16 Calculate hop noise allowance.

4.5.16.1 Initial calculation procedures are illustrated by an example. Consider the system shown in figure 4.5.11. Sites 1, 4, 7, and 9 are terminal locations where the FM signal in modulated from and



Legend
T, Terminal Station
HR, Heterodyne Repeater
— — Indicates Other Systems

Figure 4.5-11 System Outline Diagram

demodulated to baseband. At this stage of the design, we need not be concerned if the baseband is built up from or broken down to voice channels, groups or super groups at these locations, since multiplex noise will be evaluated at a later point in the design.

4.5.16.2 Sites 2, 3, 5, 6, and 8 are repeater locations. In our example, heterodyne repeaters are assumed since their noise contribution is lower than that from baseband repeaters.

4.5.16.3 Presumably, traffic density studies, frequency plans, and preliminary equipment parameter selection have been made.

4.5.16.4 For purposes of the example, assume that 600 voice channels are required between sites 1 and 9 using an FM-FDM system operating in the 7.125 to 8.400 GHz band. Two other parameters may now be considered, receiver noise figure and per-channel deviation, If equipment on hand is to be used, obtain these numbers from operations and maintenance records. If new equipment is to be used, obtain values from the manufacturers published figures. If none of these figures are available, refer to paragraph 4.4.45.13 for a realizable receiver noise figure and select a value of per channel or peak carrier deviation from table 4.5-2. For example, a 10 dB noise figure and 200 kHz per channel RMS deviation fixes the IF bandwidth at 20 MHz.

4.5.16.5 With these equipment and operating parameters we may proceed with the system calculations. The total length of the system is 300 kilometers (sum of the individual hop lengths). The total noise allowance (excluding multiplex and through-group or through-supergroup noise is therefore 900 pWO for this section (3 pWO per km).

4.5.16.6 Next one-eighth of the total noise is allocated to each of the eight radio hops. This simple procedure is used because there will not be any appreciably different thermal noise between longer and shorter hops since each will be designed to have a received signal

TABLE 4.5-2 IF Bandwidth Required as a function of Channel Capacity and Per-channel Deviation

No. Channels	Baseband Limits kHz		Baseband Bandwidth, B_b, kHz	$10 \log \frac{B_b}{b_c}$	RMS Load Factor, LF +dBm0	* Peak Carrier Deviation, ΔF, kHz	* IF Bandwidth B_{IF}, kHz	** Peak Carrier Deviation, ΔF, kHz	** IF Bandwidth B_{IF}, kHz
	Lower (f_ℓ)	Upper (f_m)							
60	12	252	240	18.89	7.78	1621	3748	2317	5138
120	60	552	492	22.0	10.79	2293	5691	3276	7657
240	60	1052	992	25.05	13.80	3243	8591	4633	11371
300	60	1300	1240	26.02	14.77	3627	9853	5181	12961
600	60	2660	2600	29.24	17.78	5128	15577	7236	19973
960	60	4028	3968	31.07	19.82	6486	21028	9266	27588
1200	316	5564	5248	32.29	20.79	7253	25633	10361	31849
1800	316	8204	7888	34.06	22.55	8882	34171	12688	41784

* 140 kHz RMS per-channel deviation (δf)

** 200 kHz RMS per-channel deviation (δf)

level (in our example) of approximately -27.5 dBm by appropriate choice of antenna size and other equipment parameters. The intermodulation noise contributions will also be a function of the equipment used (baseband repeater, IF repeater, heterodyne repeater) and will therefore be fixed regardless of hop length.

4.5.16.7 The thermal noise for each hop can be determined from figure 4.5-12 for the selected system parameters and entered on worksheet 4.5-3. This value is 12.5 pWO for each hop based on the choice of -27.5 dBm received signal level and a 600- channel system.

4.5.16.8 The equipment intermodulation plus basic noise allocation is considered in section 4.5.20. For the example, assuming dual diversity with equal gain combiners, there is 45 pWO intermodulation noise for a heterodyne repeater-to-heterodyne repeater hop and 113.5 pWO for a terminal-to-heterodyne repeater hop. Thus, hop A will contribute 113.5 pWO, B will contribute 45 pWO, etc. Such values are also entered in worksheet 4.5-3.

4.5.16.9 Feeder echo intermodulation noise contribution is somewhat more difficult to calculate, but 10 pWO is a useful first estimate for well-designed and carefully installed transmission lines of average length. The links as finally designed will no doubt differ somewhat from this first cut estimate. The 10 pWO value is also entered in worksheet 4.5-3 for each hop.

4.5.16,10 Total noise expected on each hop is the sum of the individual contributions, and the total predicted system noise is the sum of the contributions from each hop; this is compared with the total noise allocated. In the example the calculated noise is somewhat greater than the total allocated; thus, an attempt should be made to reduce each of the individual hop contributions either by selection of different equipments to reduce equipment intermodulation noise, by increasing signal levels to reduce thermal noise (while bearing in mind that too

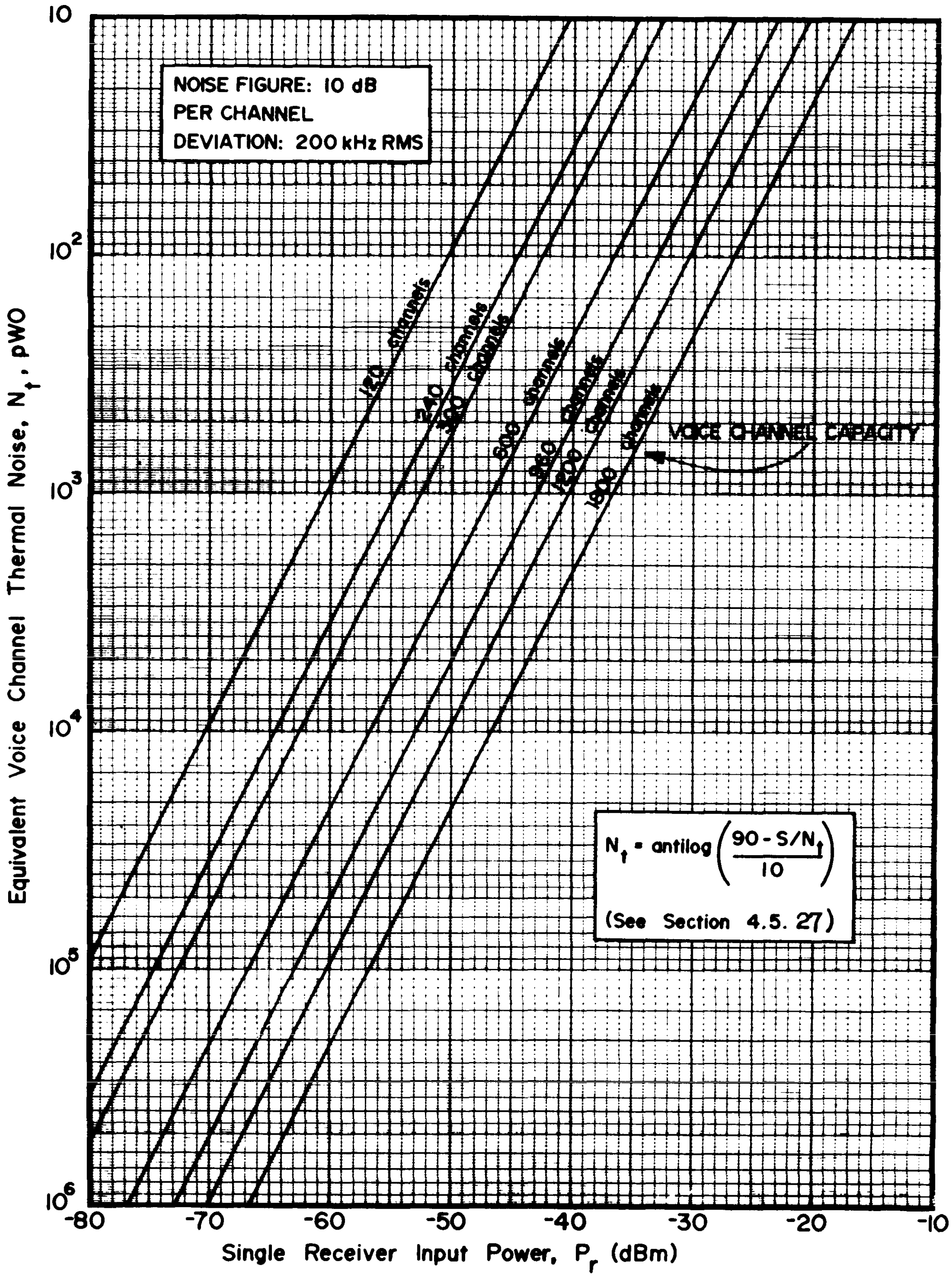


Figure 4.5-12 Thermal Noise versus Received Signal Level

Link	A	B	C	D	E	F	G	H	
Thermal Noise	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	
Equip Intermod	113.5	45	113.5	113.5	45	113.5	113.5	113.5	
Feeder Echo	10	10	10	10	10	10	10	10	
Estimated Total Noise	136	67.5	136	136	67.5	136	136	136	951 pWO
Allocated Noise	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5	Total Noise Allocated 900 pWO

Worksheet 4.5-3 Initial FM-FDM System/Hop Noise Allocation

great a signal increase can result in increased intermodulation distortion), or by assuming lower feeder echo intermodulation noise (which may necessitate the use of tuned lines or several load isolators).

4.5.17 Select basic equipment parameters

4. 5.17.1 Figure 4.5-13 illustrates qualitatively the effects on system performance (in terms of the voice channel signal-to-noise ratio) of varying frequency deviation, noise power ratio, and receiver noise figure. The arrows indicate the effects of increasing these parameters. The effect of increasing feeder echo intermodulation noise is the same as decreasing the noise power ratio. Using the methods of this section, quieting curves can be drawn for each hop for different assumed values of these parameters.

4. 5.17.2 The foregoing calculations have been made to establish the permitted long-term (median) voice channel noise. The short-term voice channel noise, in accordance with current military standards, is allocated on a per-hop basis, and shall not exceed 316, 000 pWpO for more than an accumulated two minutes in any month, or more than one minute in any hour as measured with an amplitude distribution analyzer having an integration time of 5 ms (see MI L-ST D-188-313). As always, appropriate military standards and DCA circulars (see paragraph 1.1.1) must be consulted when designing part of the DCS system. Methods for estimating short-term noise will be described in the following sections. However, a somewhat more stringent requirement based on flat weighting will be used for simplicity, namely a short-term noise level limited to 1, 000, 000 pWO which must not be exceeded for 2 minutes per year, i. e. , the noise level must be less than

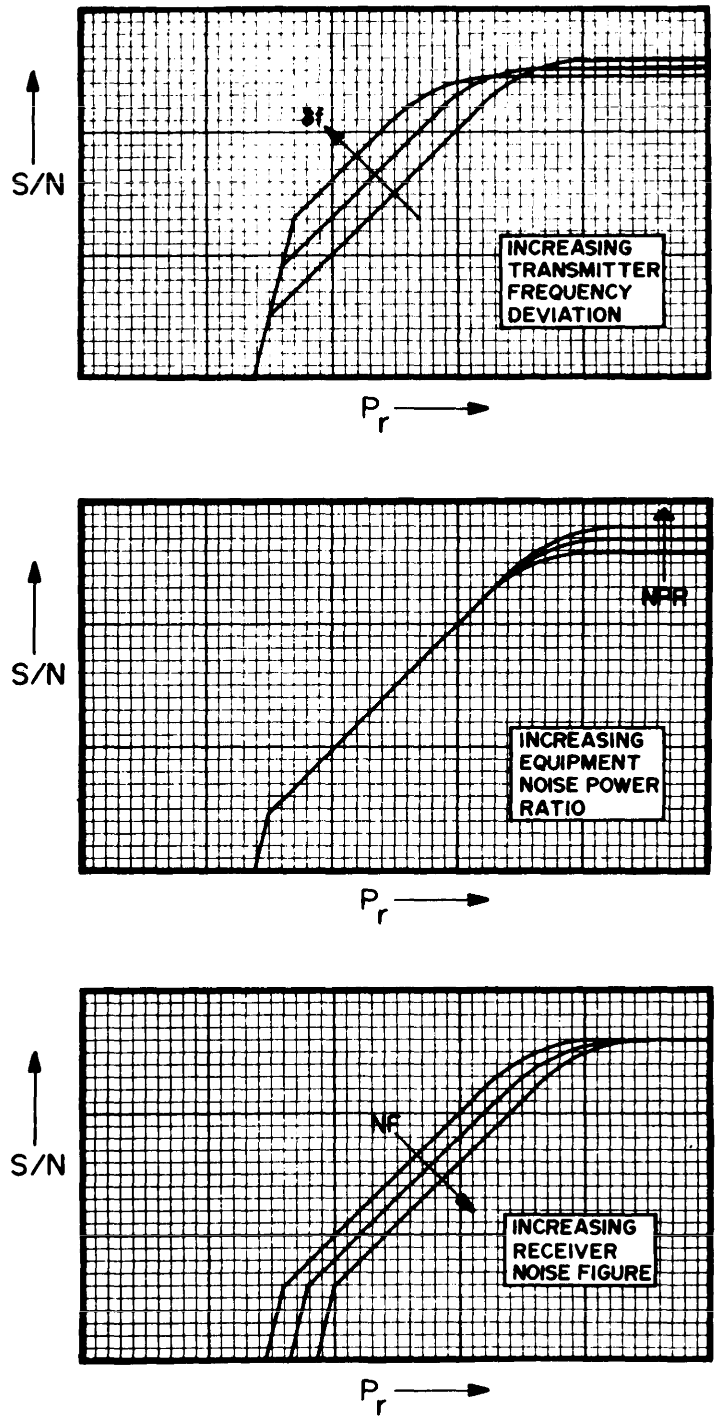


Figure 4.5-13 Effect of Parameter Variation on Transfer Characteristics

1,000,000 pWO for 99.9995% of the year. This requirement is at least equal and actually more stringent than that implied by the military standards. Although the allowable noise power is greater in the method given here (316,000 pWpO ≅ 500,000 pWO), the allowable time during which this value may be exceeded is much shorter.

4.5.17.3 After completion of the initial noise objective calculations, the next step is to fit final total median-noise predictions for each hop into the total system allocation. For this purpose, each source of noise on each hop is more precisely evaluated and combined to obtain total noise. Noise values for each hop are compared with the allocation and a compromise must often be made between incremental noise reduction (through the use of low noise preamplifiers, better waveguide installation for lower VSWR, and lower equipment intermodulation) and possible resuiting cost increases. When all hops have been evaluated, it is likely that some will be less expensive to upgrade (on paper) than others, and efforts to meet the total system median noise objectives should be concentrated on these.

4.5.17.4 Figure 4.5-14 shows a flow diagram for final single radio hop performance calculations and figure 4.5-15 shows a system noise calculation flow diagram. These diagrams illustrate schematically the processes outlined in the preceding paragraphs and described in more detail later on. A step-by-step guide through the calculations is given in worksheets 4.5-4 through 4.5-9. A complete example is demonstrated in the filled-in worksheets in section 4.5.41 at the end of this chapter.

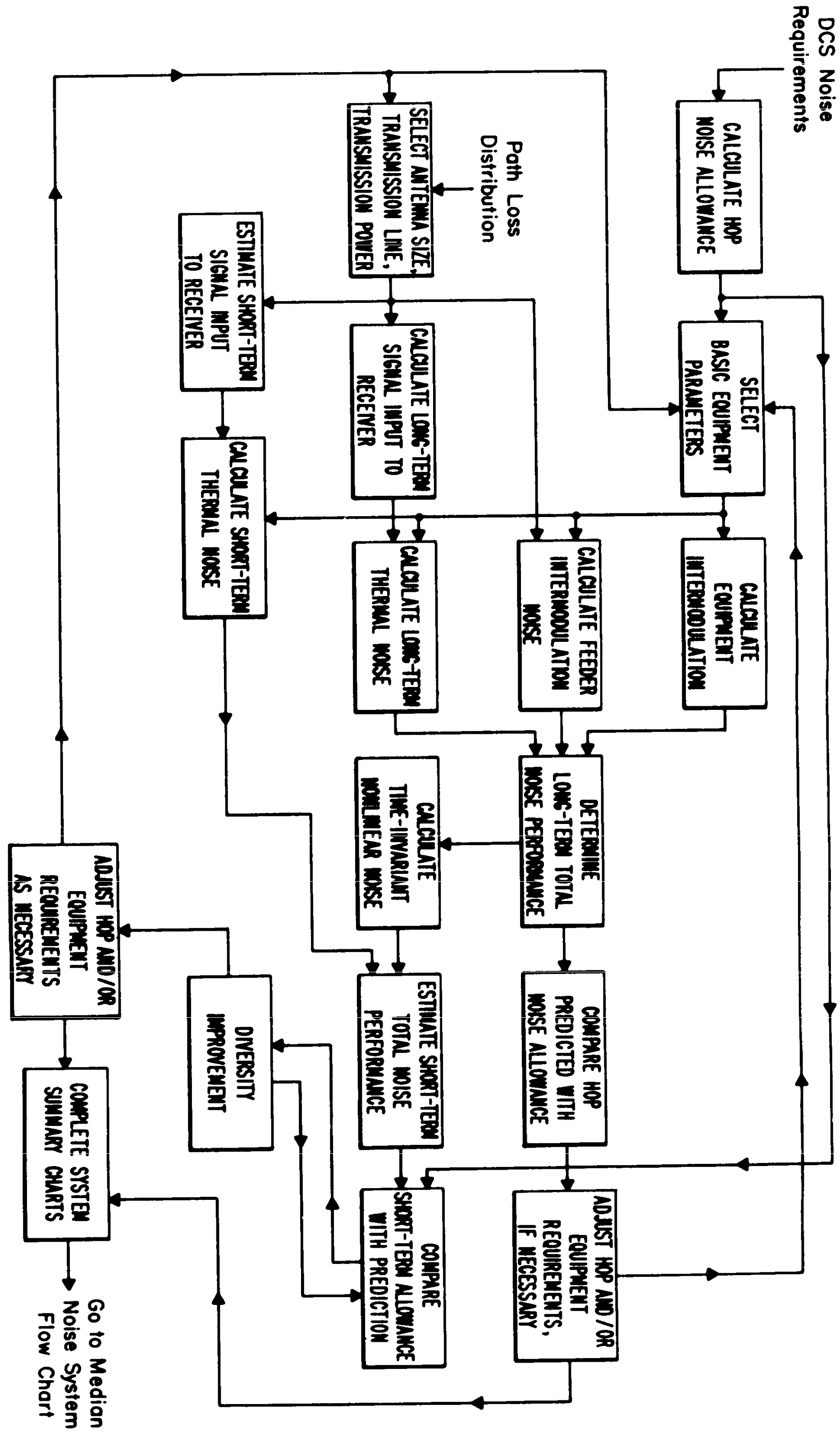


Figure 4.5-14 Hop Noise Calculation Flow Chart

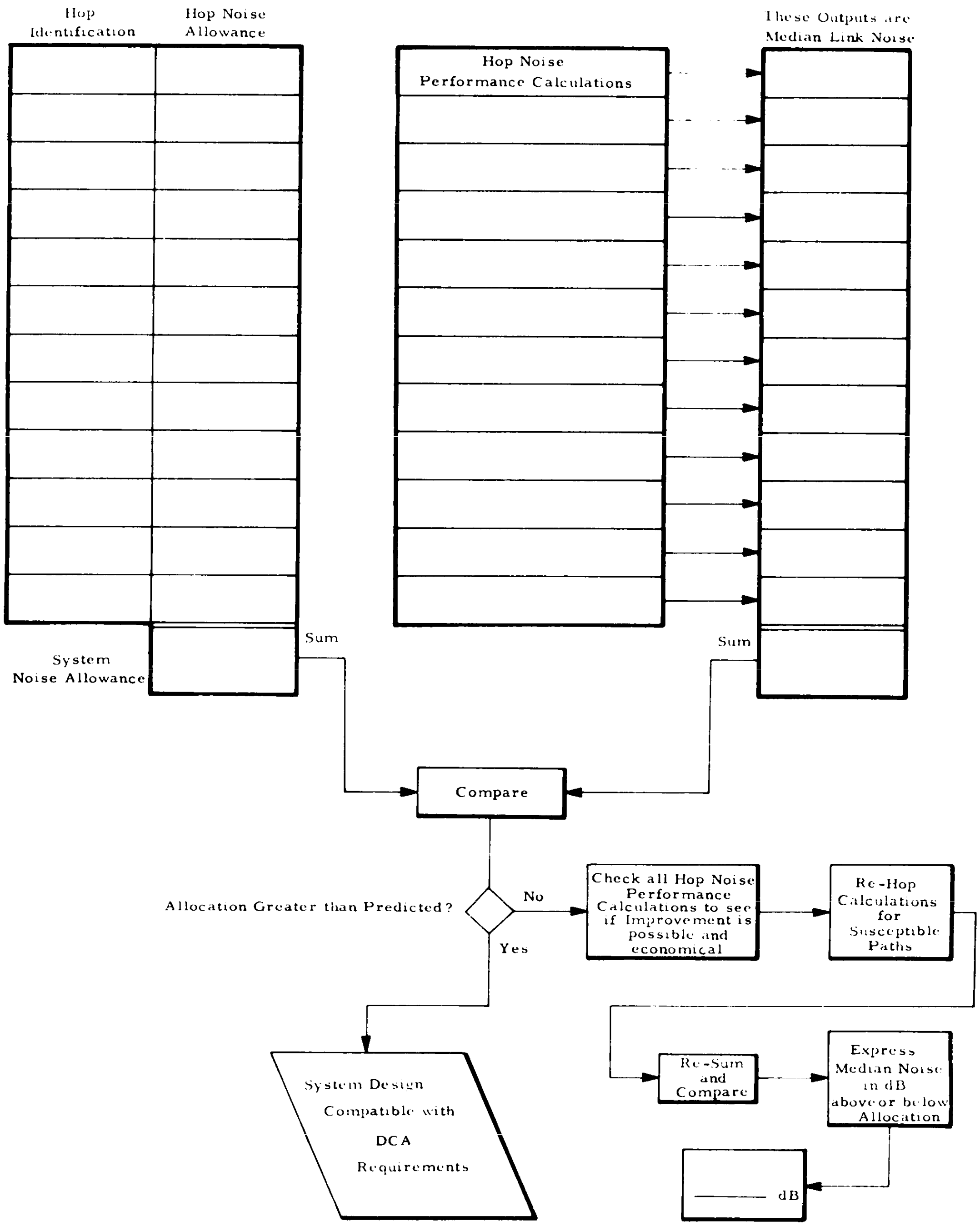


Figure 4.5-15 Median System Noise Calculation Flow Chart

4.1	Number of equivalent voice channels, n	_______		sec. 4.1.3
4.2	voice channel bandwidth, b_c	3100 Hz	(Usable bandwidth)	
4.3	maximum modulating frequency, f_m	_______kHz		table 4.5-2 (upper baseband limit)
4.4	Baseband bandwidth, B_b	_______kHz	$B_b = f_m - f_\ell$ where f_ℓ is the lowest frequency in baseband	table 4.5-2
4.5	RMS load factor, LF	_______dBm0	-10 + 10 log n	step 4.1; par. 4.5.27.2
4.6	Numerical RMS load factor ℓf	_______	antilog(LF/20)	step 4.5
4.7	peak factor, PF	13.5 dB		par. 4.5.27.2
4.8	Numerical peak factor, pf	4.73	antilog(PF/20)	step 4.7
4.9	RMS per channel deviation, δf	_______kHz		par. 4.5.16.4 & table 4.5-2
4.10	RMS carrier deviation, δF	_______kHz	$\delta F = (\ell f)(\delta f)$	steps 4.6 & 4.9
4.11	Peak carrier deviation, ΔF	_______kHz	$\Delta F = (pf)(\ell f)(\delta f)$	steps 4.6, 4.8, & 4.9
4.12	Receiver IF bandwidth, B_{IF}	_______kHz	$B_{IF} = 2(\Delta F + f_m)$	steps 4.3 & 4.11, also table 4.5-2
4.13	Receiver noise figure, F	_______dB		par. 4.5.16.4 & 4.4.45.13
4.14	Receiver noise threshold	-______dBm	-174 + 10 log B_{IF}(Hz) + F	steps 4.12, 4.13 or par. 4.5.27.2
4.15	FM improvement threshold	-______dBm	-174 + 10 log B_{IF}(Hz) + F + 10	par. 4.5.27.2
4.16	Pre-emphasis improvement, I_p	4 dB		sec. 4.5.26
4.17	Median diversity improvement, I_d	_______dB		par. 4.5.34.1 worksheet 4.4-5 step (46)
4.18	Radio set NPR	_______dB		par. 4.5.20.3

Worksheet 4.5-4. Basic Parameters for Median Noise Calculations

5.1	Transmission line or wave-guide length, transmitter	______m		worksheet 4.4-4 & sec. 4.5.19
	Type of transmission line or waveguide	______		
5.2	Percent velocity of propagation	______%v		fig. 4.5-18
5.3	Velocity of propagation, v	______m/sec	$v = (3 \times 10^8)(\%v \times 10^{-2})$	par. 4.5.21.4
5.4	Echo delay time,	______sec	$\tau = 2L/v$	par. 4.5.21.4
5.5	Radian delay	______rad	$2\pi f_m \tau$	par. 4.5.21.4
5.6	Parameter A	______	$A = \delta F/f_m$	par. 4.5.21.4
5.7	S/D - r	______dB		fig. 4.5-19 par. 4.5.21.4
5.8	Transmit system			par. 4.5.21.5
	Antenna return loss RL_{ANT}	dB		from application standards or manufacturer's specifications
	RF interface return loss RL_{RFI}	dB		
5.9	Echo amplitude, r	dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$	par. 4.5.21.5 step 5.8, & step (31) from worksheet 4.4-5
5.10	Transmit signal-to-distortion ratio, S/D	______dB	$S/D = (S/D - r) + r$	par. 4.5.21.8 steps 5.7 & 5.9
5.11	Transmit signal-to-feeder echo noise, S/N_f	______dB	$S/N_f = S/D + 10 \log \frac{B_b}{b_c} - LD$	par. 4.5.21.8
5.12	Transmit feeder echo noise, $N_{f(trans.)}$	______pWO	$N_f = \text{antilog} \frac{90 - S/N_f}{10}$	par. 4.5.21.8

Worksheet 4.5-5. Transmitter Feeder Echo Noise Calculation

6.1	Transmission line or waveguide length, receiver	______m		worksheet 4.4-4 sec. 4.5.19
	Type of line or waveguide	______		
6.2	Percent velocity of propagation	______%v		fig. 4.5-18
6.3	Velocity of propagation, v	______m/sec	$v = (3 \times 10^{8})(\%v \times 10^{-2})$	par. 4.5.21.4
6.4	Echo delay time, T	______sec	$\tau = 2L/v$	par. 4.5.21.4
6.5	Radian delay	______rad	$2\pi f_m \tau$	par. 4.5.21.4
6.6	Parameter A	______	$A = \delta F/f_m$	par. 4.5.21.4
6.7	S/D - r	______dB		fig. 4.5-19 par. 4.5.21.4
6.8	Receive system			par. 4.5.21.5
	Antenna return loss RL_{ANT}	dB		from applicable standards or manufacturer's specifications
	RF interface return loss RL_{RFI}	dB		
6.9	Echo amplitude, r	______dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$	par. 4.5.21.5 step 6.8, & step (32) from worksheet 4.4-5
6.10	Receive signal-to-distortion ratio, S/D	______dB	S/D = (S/D - r) + r	par. 4.5.21.8 step 6.7 &6.9
6.11	Receive signal-to-feeder echo noise, S/N_f	______dB	$S/N_f = S/D + 10 \log \frac{B_b}{b_c} - LF$	par. 4.5.21.8
6.12	Receive feeder echo noise, $N_{f(receive)}$	______pWO	$N_f = \text{antilog} \frac{90 - S/N_f}{10}$	par. 4.5.21.8

Worksheet 4.5-6. Receiver Feeder Echo Noise Calculation

7.1	Total feeder echo noise, N_f	______pWO	$N_f = N_{f(trans)} + N_{f(receive)}$	steps 5.12 &6.12
7.2	Signal/equipment intermodulation, S/N_e	______dB	$S/N_e = NPR + 10 \log \frac{B_b}{b_c} - LF$	steps 4.2,4.4 4.5, 4.18, & sec. 4.5.20
7.3	Equipment intermodulation noise, N_e	______pWO	$N_e = \text{antilog} \frac{90 - S/N_e}{10}$	step 7.2,& par. 4.5.20.5
7.4	Calculate $20 \log \frac{\delta f}{f_m}$	______dB		steps 4.3, 4.9 par. 4.5.27.2
7.5	Calculate $10 \log KTb_c + F$	______dBm	$-139.1 + F$	step 4.13 & par. 4.5.27.2
7.6	Signal-to-thermal noise ratio minus received signal level, $S/N_t - P_r$	______dB	$S/N_t - P_r = -10 \log KTb_c - F + 20 \log (\delta f/f_m)$	steps 7.4, 7.5 & par. 4.5.27.2
7.7	Draw quieting curve on worksheet 4.5-10			par. 4.5.27.3
7.8	$P_r(0.5) = (P_r - 3\text{ dB})$	______dBm		par. 4.5.18.1 & worksheet 4.4-5
7.9	Median signal-to-thermal noise ratio, $S/N_t(0.5)$	______dB	$(S/N_t - P_r) + P_r(0.5)$	steps 7.6, & 7.8
7.10	Median thermal noise, $N_t(0.5)$	______pWO	$N_t(0.5) = \text{antilog} \frac{90 - S/N_t(0.5)}{10}$	step 7.9
7.11	Emphasis-improved signal-to-thermal noise ratio, $S/N_{te}(0.5)$	______dB	$S/N_{te}(0.5) = S/N_t(0.5) + I_p$	steps 7.9 & 4.16
7.12	Emphasis-improved thermal noise, $N_{te}(0.5)$	______pWO	$N_{te}(0.5) = \text{antilog} \frac{90 - S/N_{te}(0.5)}{10}$	step 7.11
7.13	Total median noise, $N_T(0.5)$	______pWO	$N_T(0.5) = N_{te}(0.5) + N_f + N_e$	steps 7.12, 7.1 & 7.3

Note: Median values are denoted by (0.5).

Worksheet 4.5-7. Calculate Median Total Noise Performance

8.1	Fade margin, M_f	______dB	$P_r(0.5)$-FM Imp. Thresh., or $P_r(0.5)-30 + (S/N_t - P_r)$ whichever is smaller	steps 4.15, 7.8, and 7.9 sec. 4.5.16
8.2	Percent time M_f is exceeded, P_{mf}	______%	$P_{mf} = 6x10^{-5} a \times b \times f \times d^3 \times 10^{-(Mf/10)}$	sec. 4.2.27 and 4.5.33.1
8.3	Divide M_f by path length d or 10, whichever is less	______dB/km		
8.4	percent time fade margin is exceeded due to rain attenuation, P_{mfr}	______%	Enter value from step 8.3 as ordinate on graph of fig. 4.2-12 for the appropriate rain zone and read % time value of abscissa for carrier frequency, f	worksheet 4.4-4, step (23) worksheet 4.4-5, step (47) fig. 4.2-12
8.5	Total percent time fade margin is exceeded, P_{mft}	______%	$P_{mft} = P_{mf} + P_{mfr}$	steps 8.2 and 8.4
8.6	Received signal level at FM threshold, P_{rTH}	______dBm	$P_r(0.5) - M_f$	steps 7.8 and 8.1
8.7	Thermal signal-to-noise ratio at threshold, S/N_{tTH}	______dB	$(S/N_t - P_r) + P_{rTH}$	steps 7.6 and 8.6
8.8	Emphasis-improved, $S/N_{tin}(')$	______dB	$S/N_{tTH} + I_p$	steps 8.7 and 4.16
8.9	Emphasis-improved thermal noise at threshold, $N_{tTH}(E)$	______pWO	anilog $\frac{90 - S/N_{tTH}(E)}{10}$	step 8.8
8.10	Total path-independent non-linear noise, N_{im}	______pWO	$N_r + N_e$	steps 7.1 and 7.3
8.11	Total emphasis-improved noise at FM threshold, $N_{TTH}(E)$	______pWO	$N_{im} + N_{tTH}(E)$	steps 8.9 and 8.10
8.12	Is total noise $N_{TTH}(E)$ $\leq$ 1,000,000 pWO and percent time P_{mft} less than 5×10^{-4}?	______	(yes or no)	steps 8.5 and 8.11

Worksheet 4.5-8. Calculate Short-Term Noise Performance

8.13	If "yes", and diversity was not selected previously, link design is completed. If "no", or diversity has already been selected, continue. If "no", and diversity was not selected previously, re-do steps 4.17, 4.18, and 7.2 through 8.12; then continue.			
8.14	Plot line for non-diversity fade margin versus % of time on worksheet 4.5-11			par. 4.5.34.1 steps 8.1 &8.5
8.15	Read diversity improvement at percentage P_{mft} and other desired percentage values for type of combiner used	______ I_d (______%)		fig. 4.5-21 worksheet 4.4-4 step (46); step 8.5
8.16	Decrease fade margin values at P_{mft} and other desired percentage values by the appropriate I_d values	______dB	M_f - I_d(______%)	
8.17	Plot line for diversity-improved fade margin versus % of time on worksheet 4.5-11			step 8.16 par. 4.5.34.1
8.18	Diversity and emphasis improved thermal signal-to-noise ratio $S/N_t(E,D)$ at P_{mft} percentage of time	______dB	S/N_{tTH} + I_p + I_d(______%)	steps 8.8 & 8.15
8.19	Diversity and emphasis improved thermal noise $N_t(E,D)$ at P_{mft} percentage of time	______pWO	antilog $\frac{90 - S/N_t(E,D)}{10}$	step 8.18
8.20	Estimated total percent of outage time after diversity and emphasis improvement	______%	Read abscissa for diversity-improved fade margin line on worksheet 4.5-11 where it intersects the ordinate value for M_f	steps 8.1 & 8.17
8.21	Total noise $N_T(E,D)$ at P_{mft} percentage of time	______pWO	$N_t(E,D)$ + N_{im}	steps 8.10 &8.19
8.22	Is total noise ≤ 1,000,000 pWO	______(yes or no)	If answers are no, adjust parameters and recalculate noise performance	
8.23	Is total outage time 5 x 10^{-4}%	______(yes or no)		
8.24	If total noise cannot be reduced to ≤ 1,000,000 pWO, estimate percentage of time during which 1,000,000 pWO is exceeded	______%	Calculate ratio of total noise to 1,000,000 pWO, converted to dB, subtract from M_f, and read on the diversity improved line of worksheet 4.5-11 the percentage value corresponding to this ordinate	step 8.1 worksheet 4.5-11

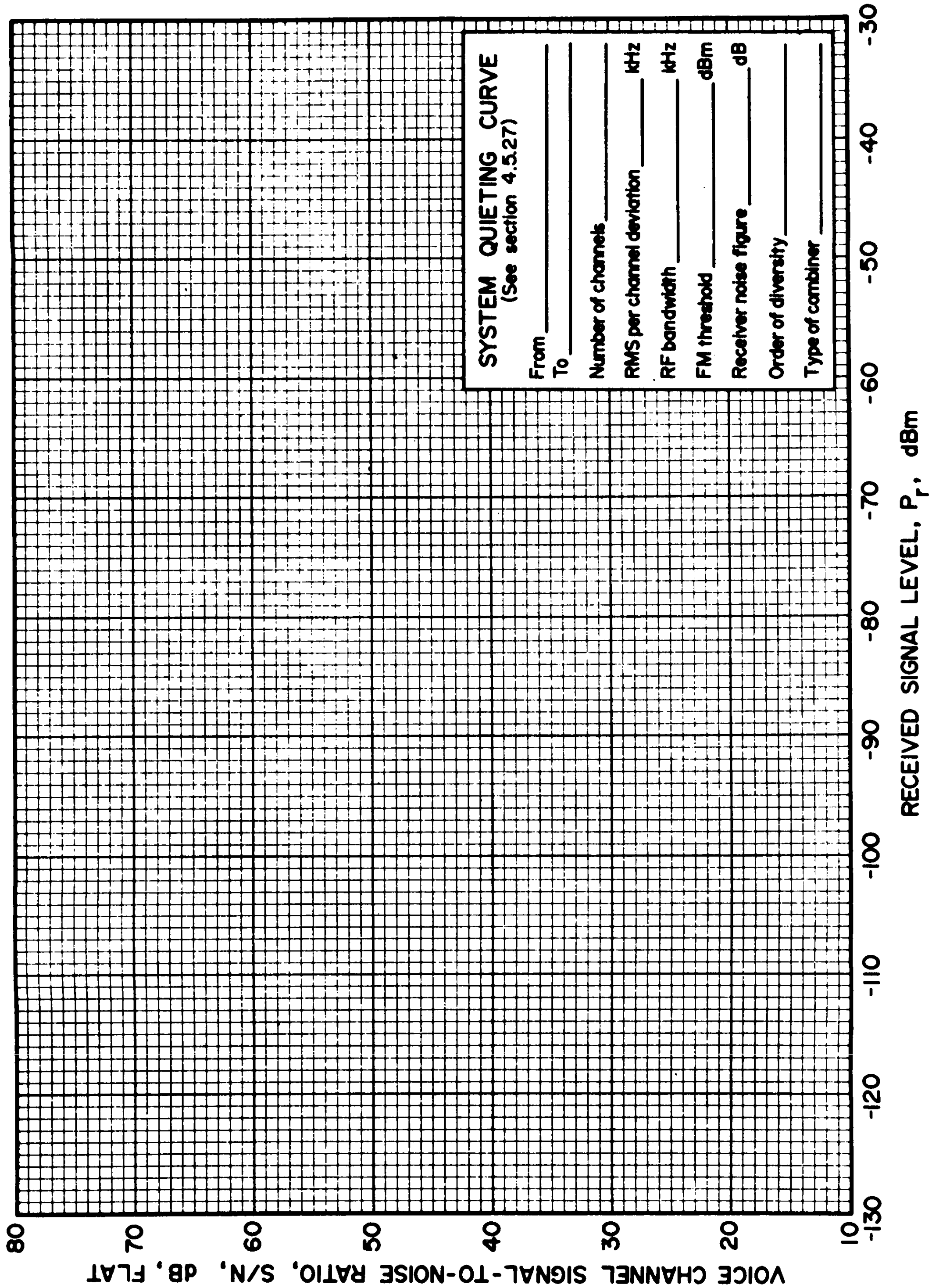
Worksheet 4.5-8. Calculate Short-Term Noise Performance (continued)

No.	Path	Terminal	No. of Channels	Hop Time Availability (Percentile)	C/N Front End (dB)	Highest BB Frequency (MHz)	Fade Margin (dB)	Diversity Improvement (dB)	Top Channel Noise Power, Unweighted (picowatts) Thermal	Intermodulation	Feeder Echo	Emphasis-Improved Thermal	Total	Total Channel S/N, flat, (dB)				Percent of Time Hop Exceeds 10^6 pW0 (flat)	Noise Allocation
TOTALS																			

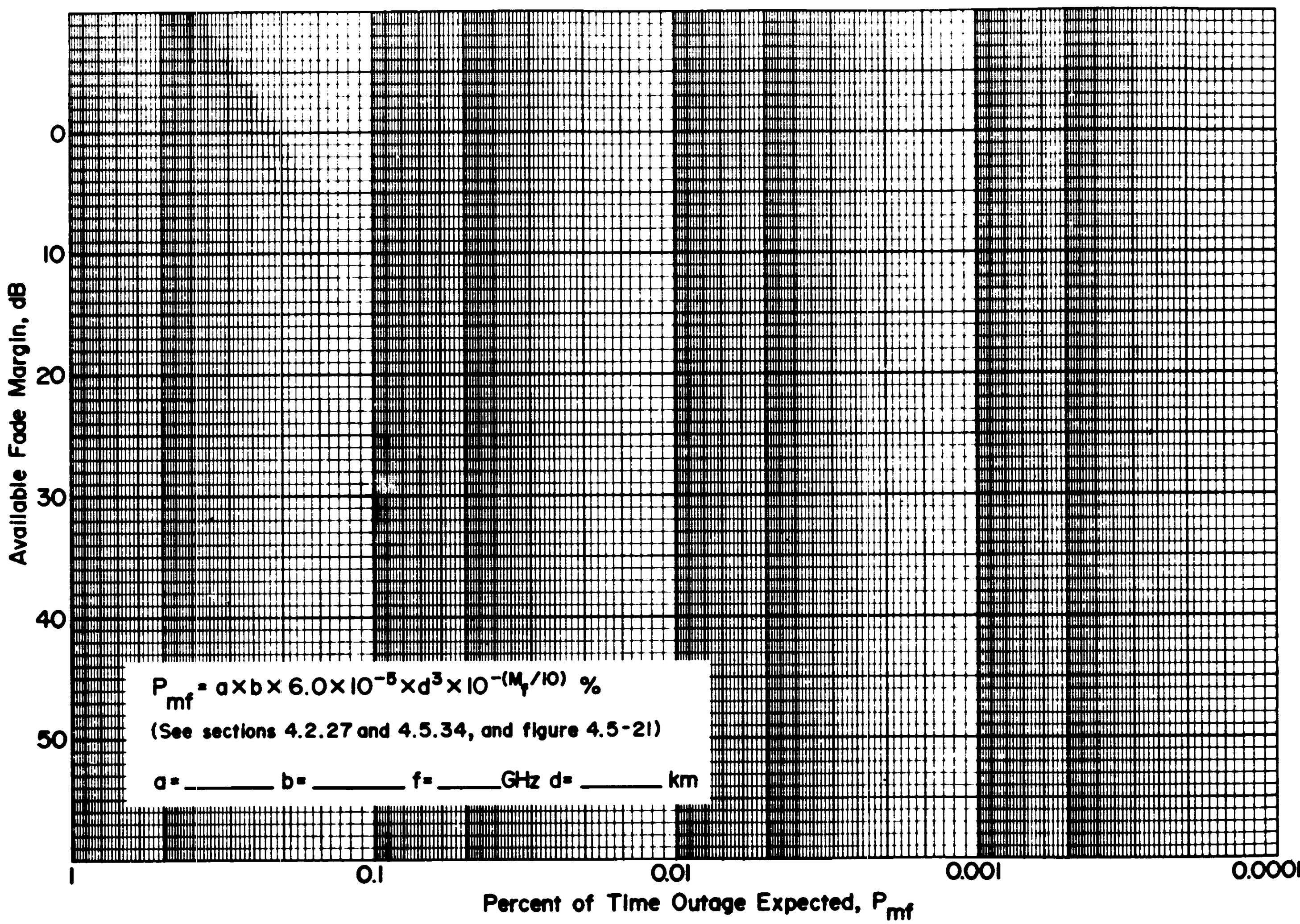
Note: If DCS noise allowance is less than predicted performance, state reasons why it could not be achieved.

Long-term DCS System Noise Allocation______pW0, based on L =______km
Long-term predicted System Noise Performance______pW0
Estimated System Outage Time______% of year,______min

Worksheet 4.5-9 FM/FDM System/Hop Noise Allocation



Worksheet 4.5-10. Graph for System Quieting Curve



Worksheet 4.5-11. Non-Diversity and Diversity Improved Fade Margins

4.5.18 Path loss distribution

4.5.18.1 The second major input to the calculations is an estimated distribution of transmission loss for each radio hop in order to estimate short-term noise. The long term median loss may be estimated to be 3 dB greater than the sum of the free-space loss and the atmospheric attenuation (see Section 4.2.22). The desired short term reliability has already been defined as 99.9995% corresponding to approximately two minutes per hop per year when the voice channel noise is allowed to exceed 1,000,000 pWO. Noise values of this magnitude in a voice channel are usually thermal caused by a marked increase in transmission loss. (We will not consider at this time severe equipment problems or the even more unlikely occurrence of strong RF interference.)

4.5.18.2 The likelihood of such thermal noise bursts or noise increases in a voice channel are related also to the available fade margin for each radio hop.

4.5.18.3 Fade margin as used here is defined as the decibel difference in power levels between the normal unfaded signal (which corresponds to the long-term median loss; see paragraph 4.5.18.1) and either the FM threshold level or that received signal level where the thermal noise equals 10^6 pWO whichever will give the smaller fade margin. For these calculations, other noise contributions can usually be neglected. To illustrate, consider figures 4.5-16 and 4.5-17. On figure 4.5-16, note that for a voice channel capacity of 120 or greater, the thermal noise exceeds 10^6 pWO at FM threshold so the fade margin is the difference in P_r (in dB) between the median value of P_r and that value of P_r where the channel capacity thermal noise curve crosses the 10^6 pWO noise level. Thus, for the 600-channel system with 140 kHz RMS per-channel deviation (on figure 4.5-16) with a median P_r of -27.5 dBm, the 600 channel curve intersects the 10^6 -pWO level at P_r = -73.5 dBm. This results in a fade margin of 46.0 dB. For a per-channel RMS frequency deviation of 200 kHz (as shown in figure 4.5-17), the thermal noise level of 10^6 pWO intersects the 600-channel curve at -76.5 dBm which results in a fade margin of 49.0 dB for the same median value of P_r. Thus the fade margin can be increased by increasing the per-channel deviation. The fade margin decreases with increased channel capacity.

4.5.18.4 So far we have discussed fade margin and its calculation for the individual radio hops in the system. The fade margin required for each hop to maintain desired link reliability and ways to achieve the increased margin which may be necessary on difficult links will be discussed in section 4.5.33.

4.5.19 Select antenna size, transmission line, transmitter power, and calculate long-term median receiver input power

4.5.19.1 At this point, we are ready to begin the calculations required for the link design summary on worksheet 4.4-4. Items 1 through 16 are now known and the appropriate entries have been made. Items 23, 25, and 26 are also known so a tentative selection of transmission line or waveguide type (items 27 and 28) can be made which leads to the values for waveguide loss per unit length (items 29 and 30), and to total waveguide losses

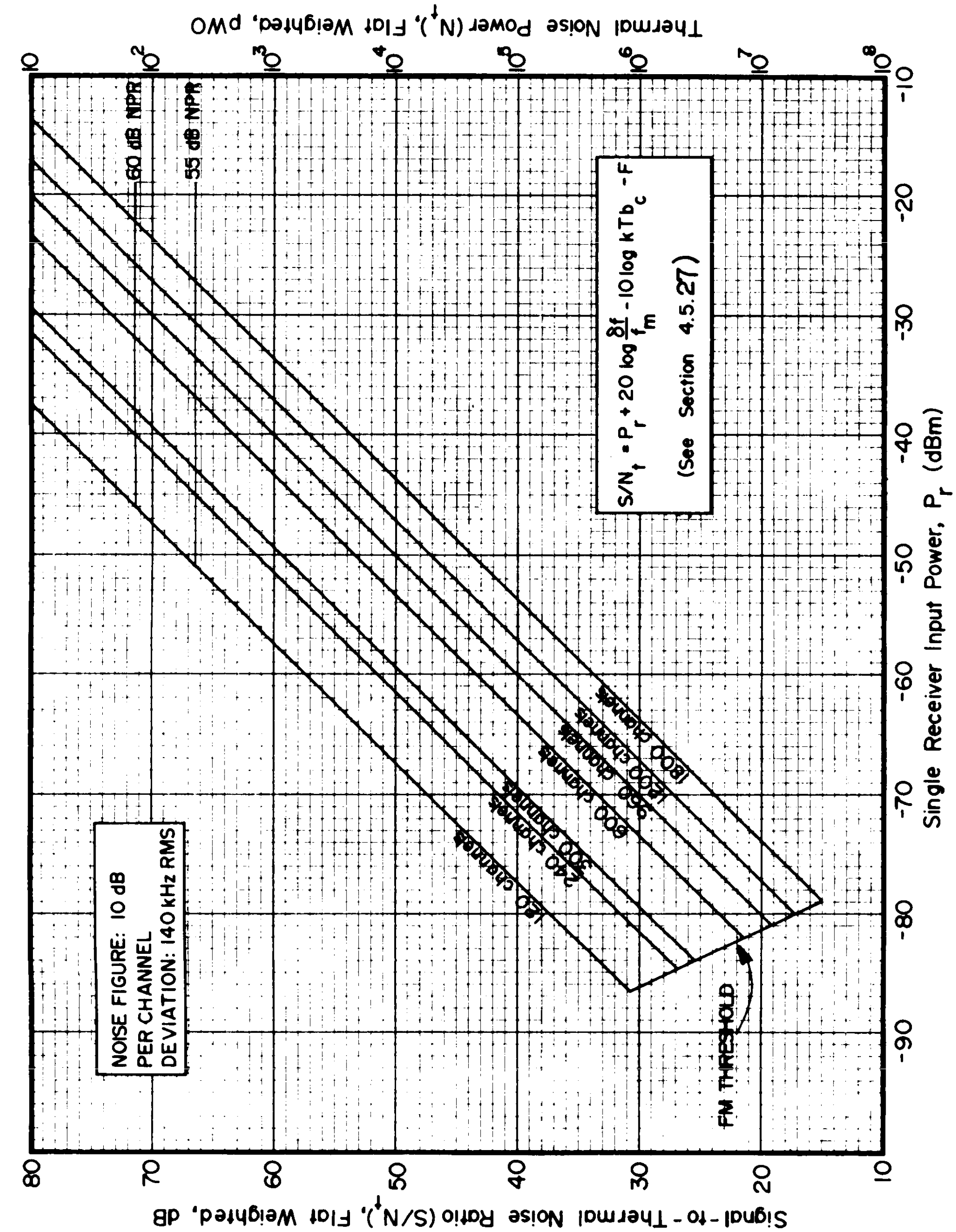


Figure 4.5-16 S/N_t versus Received Signal Level

where Per Channel Deviation is 140 kHz

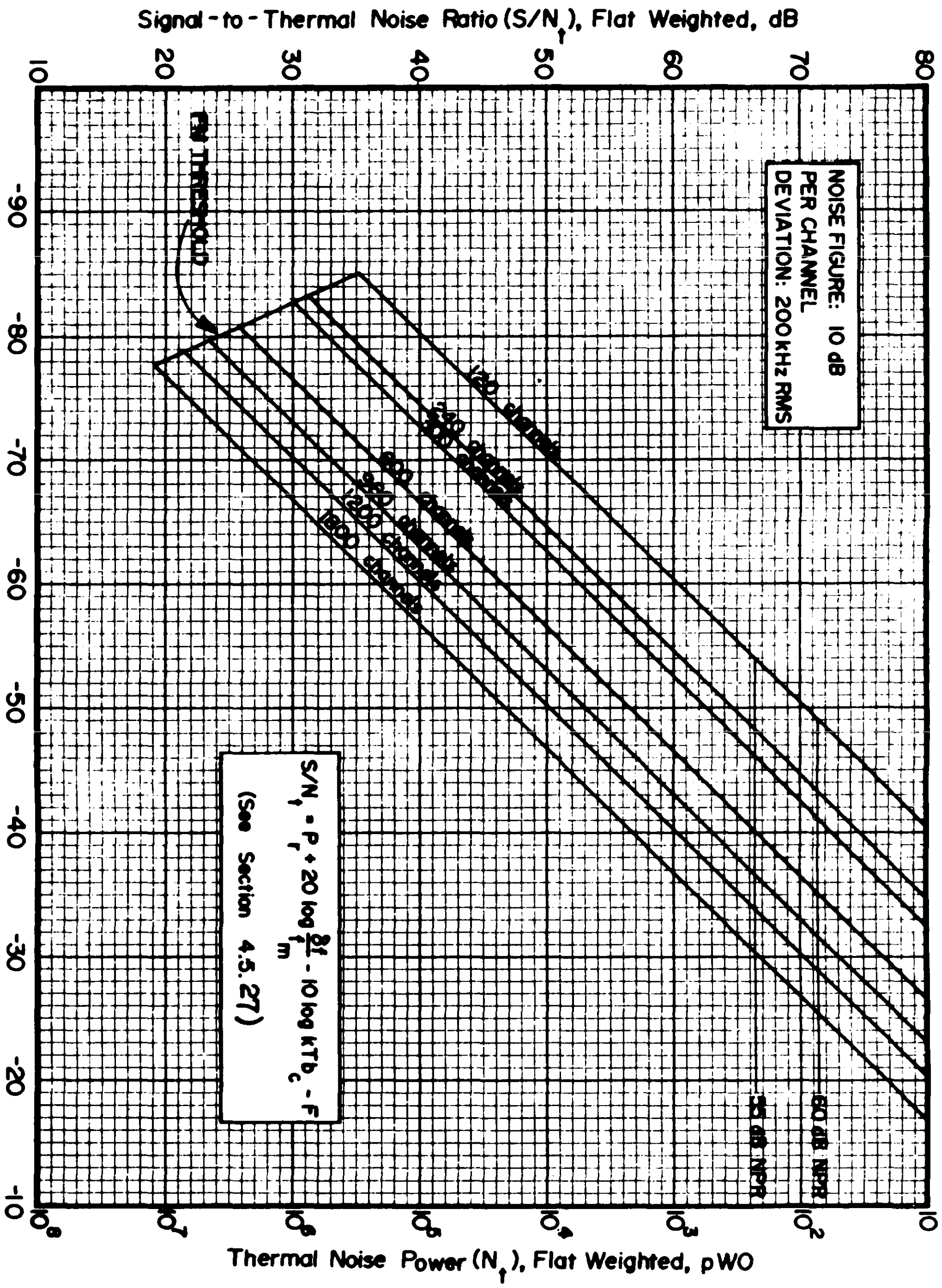


Figure 4.5-17 S/N$_t$ versus Received Signal Level
where Per Channel Deviation is 200 kHz

(items 31 and 32). Typical values should now be chosen for circulator losses (items 33 and 34) and the net fixed losses (item 35) calculated. However, these values (items 27 through 35) are tentative estimates which may be changed as radio hop requirements dictate.

4.5.19.2 The next step is the calculation of free-space basic transmission loss (item 38) using item 37, path length (from the path profile) and item 23, carrier frequency. Item 39, the average atmospheric absorption, is obtained from Section 4.2.22. Since the expected median receiver input power was initially assumed to be -27.5 dBm, it can be used in conjunction with the net loss (item 40) to yield the total gain required to produce this desired received signal level value over the path. As a first estimate, a transmitter power of +30 dBm (1 watt) can be used for item 36; this value subtracted from the sum of items 40 and 42 will be the sum of the required antenna gains (items 21 and 22).

4.5.19.3 Consider one of the hops from the example system, in order to illustrate quantitative results. Hop H between sites 8 and 9 (figure 4.5-11) is 43 kilometers long, will operate with space diversity and will transmit from site 9 at 8.250 GHz and from site 8 at 8.150 GHz. Forty-meter towers are assumed necessary at each site, which means that about 48 meters of waveguide will be required per site. Consider elliptical waveguide, EW71, which has 6.3 dB loss per 100 meters and 0.5 dB transmit and 1 dB receive circulator and filter losses. This results in 7.5 dB for item 35 (worksheet 4.4-5), net fixed losses. Since transmitter power is expensive, assume initially one watt or +30 dBm. For the average frequency of 8.2 GHz and a path length of 43 km a free-space basic transmission loss value of 143.3 dB is obtained. From paragraph 4.2.22.2 the atmospheric absorption is found to be 0.4 dB. Item 40, the net loss is 154.3 dB and if we subtract the difference between +30 dBm for transmitter power and -27.5 dBm for median received signal level, the required antenna gain is 96.8 dB. This implies an antenna diameter of 13.5 ft for equal antennas at both sites (from figure 4.4-30).

4.5.19.4 At this point we must consider recommended limits on antenna size given in figure 4.4-33. The maximum diameter for 0.5° half-power beamwidth is about 16 ft and the recommended diameter is 10 ft. Although 15-ft dishes can meet the median signal requirements, alternative ways to reduce system loss should be explored in order to avoid extremely narrow antenna beams (see discussion in Section 4.4.29). As an example 12-ft dishes with 47.2 dB gain and RF preamplifiers at the receiving antennas could be used. This would reduce the line loss by 3 dB and maintain the desired median signal level. The use of RF preamplifiers was discussed in paragraph 4.4.45.12 and illustrated in figure 4.5-2. It also has the advantage that the receiver noise figure is reduced which further increases the fade margin.

4.5.20 <u>Equipment intermodulation noise calculation</u>

4.5.20.1 A message passing through a microwave radio relay system is present in either of two basic forms: as an amplitude -modulated or frequency-modulated signal. The signal is normally transmitted from one station to anot her in frequency-modulated form, demodulated and processed in amplitude-modulated form and re-transmitted in frequency-modulated form. The presence of modulation in either form causes instantaneous nonsinusoidal changes in either voltage or frequency within microwave circuits. Because such circuits cannot be made completely linear, and cannot respond instantaneously to such changes in voltage or frequency, spurious signals are produced by each channel in the system and occur across a wide frequency range. Although the spurious signals produced in each channel are very small, the additive effect from a large number of signals in several channels beating together forms intermodulation noise signals whose amplitude is large enough to impair the performance of communications links. Some of these spurious signals will fall within the bandwidth of adjacent channels, causing inter modulation noise to appear there. The magnitude of the intermodulation noise is a function of equipment characteristics, the number of channels in the system, and the modulation levels in the channels producing the noise. The higher the modulation level in the channels producing the spurious signals, the higher the intermodulation noise will be in those adjacent channels whose bandwidths coincide with the frequencies of these noise products. The values of the intermodulation noise under specific channel loading conditions must be obtained from equipment performance specifications, or the intermodulation noise must be measured under actual operating conditions.

4.5.20.2 Intermodulation noise, for the purpose of system noise calculations, is defined as the total noise from all sources produced as a result of the presence of a modulated signal in the system. Intermodulation noise is measured in a channel with all modulation removed from the channel being measured, and with all remaining channels loaded with actual traffic or with an equivalent amount of white (randomly-distributed) noise over a specific bandwidth. The intermodulation noise power in the channel is then equal to the measured total noise with modulation present less the measured thermal noise with no modulation present.

4.5.20.3 A common method of determining total noise under maximum traffic conditions consists of using a “white noise” generator which produces a noise spectrum approximating that produced in a multichannel multiplex system. The output noise level from the generator is adjusted to a desired multiplex composite baseband level (composite noise power). Then, a notched filter is switched in to clear a narrow slot in the spectrum of the noise signal, and a noise analyzer is connected at the output of the system. The analyzer can be used to measure the ratio of composite noise power to the noise power in the cleared slot, which is equivalent to the total noise (thermal plus intermodulation) present in the slot bandwidth. Usually, the slot bandwidth is made equal to the bandwidth of a single multiplex channel; thus the noise power in the slot is the same as the total noise in a typical multiplex channel. Usually, measurements are made at the upper, lower and center frequencies of the baseband. The ratio of the composite noise power in the baseband to the total noise power in the slot is usually called the noise power ratio. (NPR). When this NPR measurement is made at high RF levels, corresponding to the median received in a back-to-back configuration, the dominant component of noise is that due to equipment intermodulation. This parameter is used as an approximation of the equipment intermodulation noise contribution, and should be obtained from operations and maintenance records or from published manufacturers' specifications on the equipment to be used including the stated equivalent noise loading. If information is not available, an NPR value of 55 dB obtainable using new, quality equipment is probably the highest value that can be assumed for the initial estimate. However, some methods of diversity combining can also improve the NPR. As an example, for equal gain or maximal ratio combining the signal powers are added coherently while intermodulation noise contributions- similar to other types of noise- are added randomly. This justifies a 3 dB improvement in NPR valuesassumed for the examples discussed here (section 4.5.16 and worksheets of section 4.5.41).

4.5.20.4 The above discussions hold for demodulating (baseband) radios. If the designer is concerned with heterodyne repeaters, the above measurements become very difficult to make, and the designer has to rely on manufacturers specifications. Alternatively, a 4 dB improvement in NPR [14] over the demodulating radio may be assumed. For example, if a 55 dB NPR is assumed for the demodulating radio, a 59 dB NPR would be used for a similar heterodyne unit.

4.5.20.5 The noise power ratio can now be converted to an equivalent noise channel signal-to-equipment inter modulation noise ratio, S/Ne, and additionally to equipment intermodulation noise, Ne. This is expressed, in dB, as:

$$S/N_e = NPR + 10 \log (B_b/b_c - LF) dB \tag{4.5-1}$$

$$Ne = \text{antilog} \frac{90 - S/Ne}{10} \text{ pWO*} \tag{4.5-2}$$

where B_b is the baseband width,

b_c is the nominal voice channel bandwidth, 3100 Hz, and

LF is the RMS load factor in dB (see Section 4.5.27).

B_b and b_c must be in the same units.

4.5.20.6 Allocation of calculated noise is difficult particularly for mixed systems on a hop; i.e., a demodulating transmitter at one end and a heterodyne repeater receiver at the other end. Very little information exists on the noise contribution of the individual components or even that of the transmitter and receiver separately. For an engineering estimate, the equipment intermodulation noise may be allocated in equal parts to the transmitter side and the receiver side.

4.5.20.7 The foregoing calculations are for the top voice channel of the system which is normally assumed to be the “worst” channel in terms of noise and performance.

4.5.20.8 Equipment intermodulation noise is considered to be independent of path loss or received signal level variations. Consequently, it will be considered as a component of the time invariant nonlinear noise (figure 4.5-14).

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*It should be noted that in the noise calculations of these sections flat-weighted noise will be used for ease in handling. If the designer desires to use other noise weighings, appropriate factors may be included at the conclusion of the design procedure.

4.5.21 Feeder intermodulation noise calculation

4.5.21.1 If a transmission line many wavelengths long is mismatched at both the generator and load ends, its frequency-phase response is linear with a small sinusoidal ripple, and this leads to reflected waves in the line that cause distortion of an FM signal. This type of distortion is more conveniently considered as being caused by an echo signal generated in a mismatched line, which results in inter modulation distortion. Significant levels of this type of intermodulation noise are reached when the waveguide lengths exceed approximately 20 meters per individual antenna, or 30 meters total per hop.

4.5.21.2 The feeder intermodulation noise is also considered to be independent of path loss or signal level variations and is therefore another component of the time invariant non-linear noise power.

4.5.21.3 Calculations of feeder intermodulation noise is well treated in the literature [13], [80]. It may be approximated given transmission line lengths (worksheets 4.5-5 and 4.5-6), velocity of propagation in the lines, transmission system component VSWR's and directional losses. The calculations are performed separately for each end of a hop; i. e., transmitter and receiver, and the results are summed to determine the total hop contribution. Procedures are as follows:

4.5.21.4 Determine echo delay time, τ, from the transmission line length, L, and the percent velocity of propagation, (% v), obtained from figure 4.5-18, using:

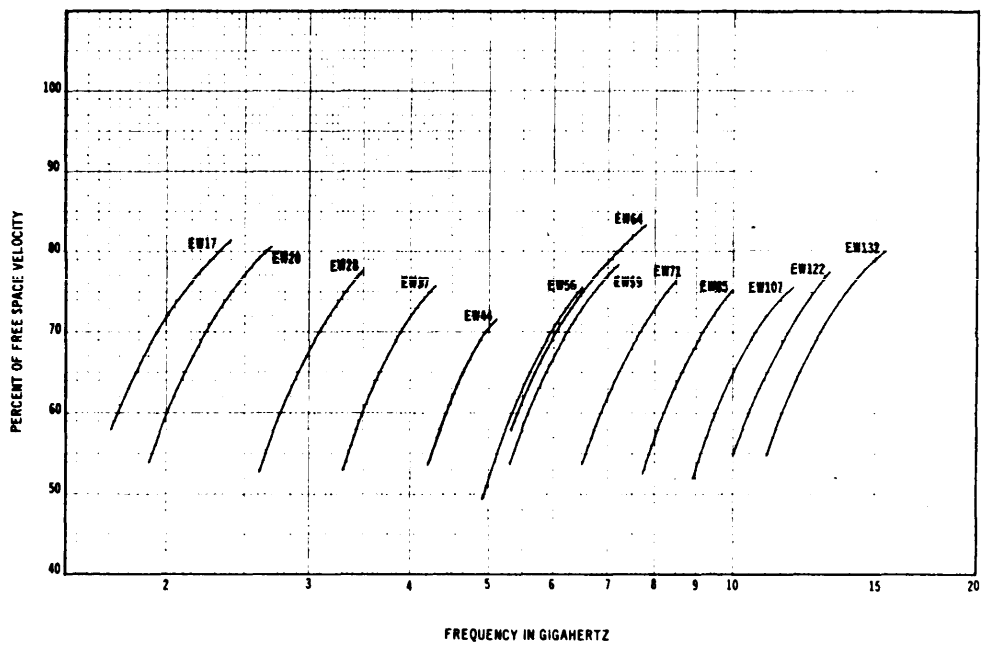
$$\tau = 2L/V \text{ sec, where } V=(3\times10^{8})(\%v\times10^{-2})\text{m/sec.} \qquad (4.5\text{-}3)$$

The echo delay time is then converted to radian delay:

$$\text{Radian delay} = 2\pi f_m \tau, \qquad (4.5.\text{-}4)$$

Courtesy of Dr. John Osepchuk and Horizon House, Inc.

VELOCITY OF PROPAGATION FOR ELLIPTICAL WAVEGUIDE



VELOCITY OF PROPAGATION FOR RECTANGULAR WAVEGUIDE

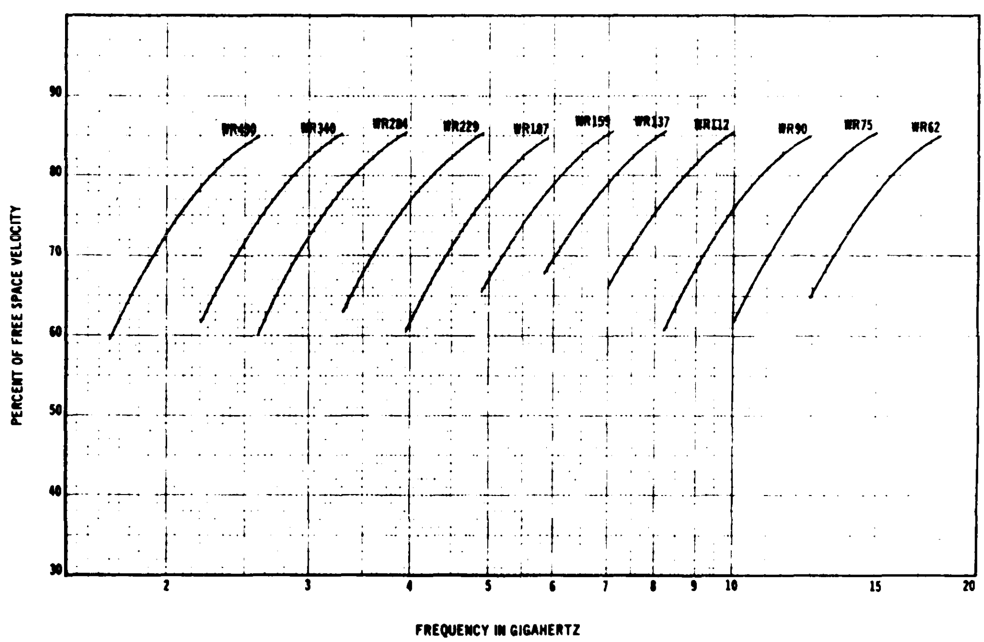


Figure 4.5-18 Waveguide Velocity Curves

where f_m is the highest modulating frequency in the baseband. Next a " parameter A " is determined from the following equation:

$$A = \delta F / f_m \qquad (4.5\text{-}5)$$

where δF is the composite RMS carrier deviation (δF is the product of δf and ℓf) and f_m as defined earlier. The symbol ℓf is the numerical load factor, antilog LF/20. Using the parameters A and the radian delay, a value for signal-to-distortion ratio minus echo amplitude, (S/D - r), may be determined from the curves in figure 4.5-19.

4.5.21.5 It now remains to determine the echo attenuation, r. Consider the top illustration in figure 4.5-19a. The echo energy at the transmitter side travels along the path shown, and is reduced by each reflection at an interface by the return loss associated with the voltage standing wave radio (VSWR) at that interface. Such values of return loss (or VSWR) must be measured with the equipment in its operating configuration. Return loss values for the radio frequency interface, the antenna input, and the transmission line (measured at the point where it connects to the RF interface with the antenna connected) my be assumed to be at least 26 dB corresponding to a VSWR value of 1 : 1.10. However, return loss values of 32 dB or better corresponding to VSWR values of 1 : 1.05 are not unrealistic, and are frequently specified. The relations between return loss, reflection coefficient, and standing wave ratio are given in the next paragraph.

4.5.21.6 The echo energy is reduced by the return loss at the

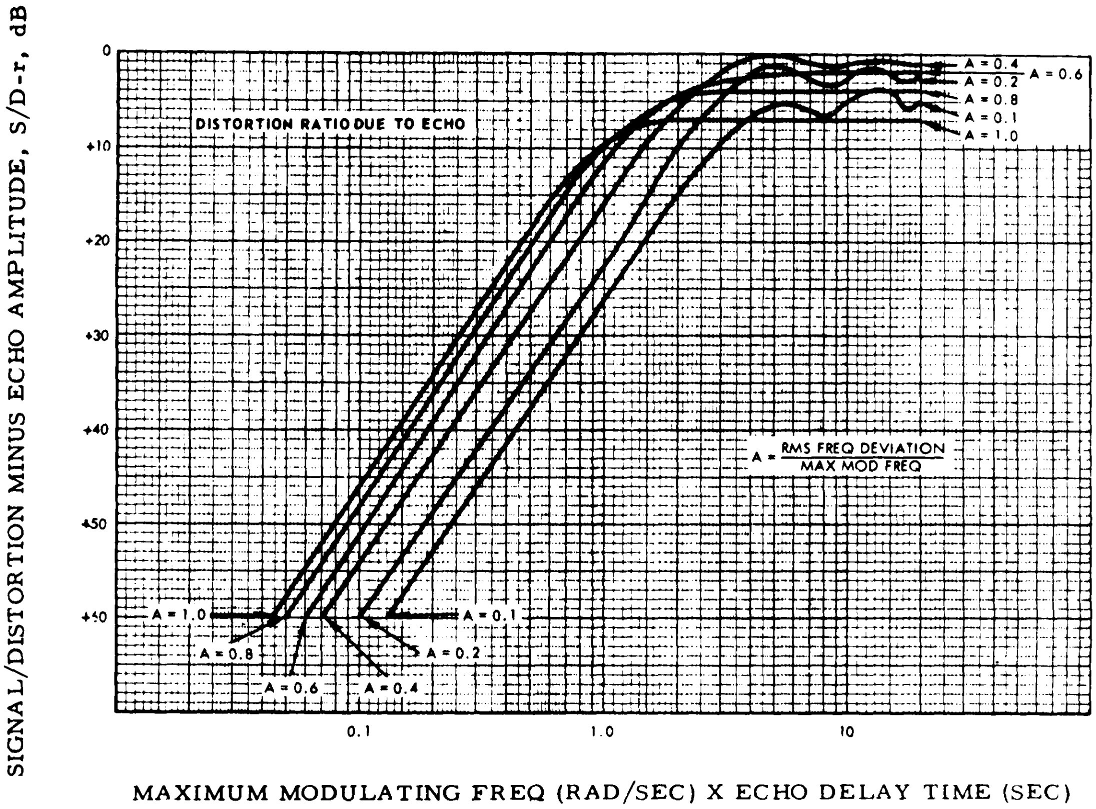
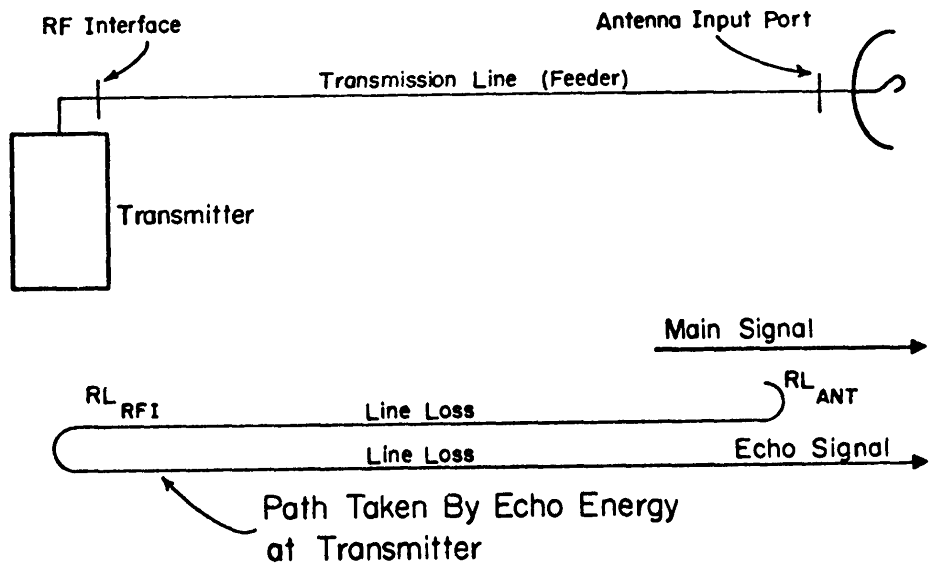


Figure 4.5-19 Maximum Distortion to Signal Ratio due to Echo



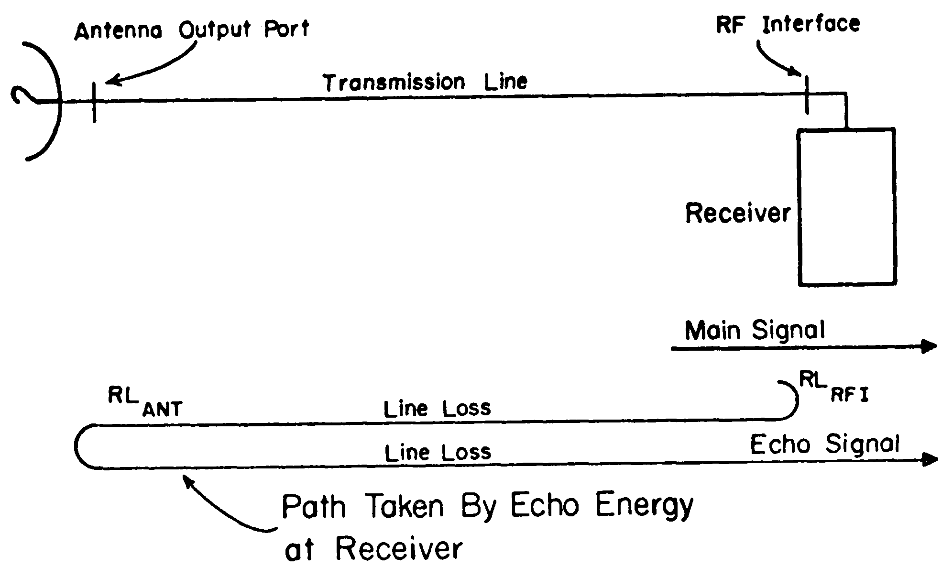


Figure 4.5-19a Illustration of Principal Signal Echo Paths

antenna port, the one -way attenuation through the transmission line antenna feeder, the return loss at the RF interface, and another one-way attenuation through the same line. The total echo attenuation in dB is thus the sum of these decibel losses. Similar considerations apply to the echo attenuation at the receiver side as shown in the lower portion of figure 4.5-19a. If parameters other than return loss are provided such as the VSWR or the voltage reflection coefficient, ρ, they can be converted to return loss, RL, using the following expressions:

$$\rho = \frac{VSWR-1}{VSWR+1} \qquad (4.5\text{-}6)$$

$$RL = 20 \log (1/\rho) \qquad (4.5\text{-}7)$$

Also, table 4.5-3 or figure 4.5-20 can be used for this conversion.

4.5.21.7 The approach described above is somewhat conservative, and may slightly overestimate voice channel feeder echo noise since it assumes that the reflections of the echo energy will result in maximum delay time and hence in nearly maximum noise. This occurs because the echo energy arriving at the RF interface in the case of the transmitter (or the antenna in the case of the receiver) in fact contains components that have been reflected at many intermediate points along the transmission line (such as waveguide joints or transitions). All of these have shorter delay times than the total echo path.

4.5.21.8 The calculation of echo attenuation (separately for transmitter and receiver) outlined above can now be converted to voice channel noise. To do this, the total echo attenuation, r, is added to the (S/D - r) value obtained from the procedures in paragraph 4.5.21.4. This results in the signal-to-distortion ratio, S/D which

VSWR	ρ	RL(dB)	VSWR	ρ	RL(dB)	VSWR	ρ	RL(dB)	VSWR	ρ	RL(dB)
1.001	0.0005	66.025	1.041	0.0201	33.941	1.081	0.0389	28.196	1.142	0.0663	23.571
1.002	0.0010	60.009	1.042	0.0206	33.736	1.082	0.0394	28.093	1.144	0.0672	23.457
1.003	0.0015	56.491	1.043	0.0210	33.536	1.083	0.0398	27.992	1.146	0.0680	23.346
1.004	0.0020	53.997	1.044	0.0215	33.341	1.084	0.0403	27.892	1.148	0.0689	23.235
1.005	0.0025	52.063	1.045	0.0220	33.150	1.085	0.0408	27.794	1.150	0.0698	23.127
1.006	0.0030	50.484	1.046	0.0225	32.963	1.086	0.0412	27.696	1.152	0.0706	23.020
1.007	0.0035	49.149	1.047	0.0230	32.780	1.087	0.0417	27.600	1.154	0.0715	22.914
1.008	0.0040	47.993	1.048	0.0234	32.602	1.088	0.0421	27.505	1.156	0.0724	22.810
1.009	0.0045	46.975	1.049	0.0239	32.427	1.089	0.0426	27.411	1.158	0.0732	22.708
1.010	0.0050	46.064	1.050	0.0244	32.256	1.090	0.0431	27.318	1.160	0.0741	22.607
1.011	0.0055	45.240	1.051	0.0249	32.088	1.091	0.0435	27.226	1.162	0.0749	22.507
1.012	0.0060	44.489	1.052	0.0253	31.923	1.092	0.0440	27.135	1.164	0.0758	22.408
1.013	0.0065	43.798	1.053	0.0258	31.762	1.093	0.0444	27.046	1.166	0.0766	22.311
1.014	0.0070	43.159	1.054	0.0263	31.604	1.094	0.0449	26.957	1.168	0.0775	22.215
1.015	0.0074	42.564	1.055	0.0268	31.449	1.095	0.0453	26.869	1.170	0.0783	22.120
1.016	0.0079	42.007	1.056	0.0272	31.297	1.096	0.0458	26.782	1.172	0.0792	22.027
1.017	0.0084	41.485	1.057	0.0277	31.147	1.097	0.0463	26.697	1.174	0.0800	21.934
1.018	0.0089	40.993	1.058	0.0282	31.000	1.098	0.0467	26.612	1.176	0.0809	21.843
1.019	0.0094	40.528	1.059	0.0287	30.856	1.099	0.0472	26.528	1.178	0.0817	21.753
1.020	0.0099	40.086	1.060	0.0291	30.714	1.100	0.0476	26.444	1.180	0.0826	21.664
1.021	0.0104	39.667	1.061	0.0296	30.575	1.102	0.0485	26.281	1.182	0.0834	21.576
1.022	0.0109	39.267	1.062	0.0301	30.438	1.104	0.0494	26.120	1.184	0.0842	21.489
1.023	0.0114	38.885	1.063	0.0305	30.303	1.106	0.0503	25.963	1.186	0.0851	21.403
1.024	0.0119	38.520	1.064	0.0310	30.171	1.108	0.0512	25.809	1.188	0.0859	21.318
1.025	0.0123	38.170	1.065	0.0315	30.040	1.110	0.0521	25.658	1.190	0.0868	21.234
1.026	0.0128	37.833	1.066	0.0319	29.912	1.112	0.0530	25.510	1.192	0.0876	21.151
1.027	0.0133	37.510	1.067	0.0324	29.785	1.114	0.0539	25.364	1.194	0.0884	21.069
1.028	0.0138	37.198	1.068	0.0329	29.661	1.116	0.0548	25.221	1.196	0.0893	20.988
1.029	0.0143	36.898	1.069	0.0333	29.538	1.118	0.0557	25.081	1.198	0.0901	20.907
1.030	0.0148	36.607	1.070	0.0338	29.417	1.120	0.0566	24.943	1.200	0.0909	20.828
1.031	0.0153	36.327	1.071	0.0343	29.298	1.122	0.0575	24.808	1.210	0.0950	20.443
1.032	0.0157	36.055	1.072	0.0347	29.181	1.124	0.0584	24.675	1.220	0.0991	20.079
1.033	0.0162	35.792	1.073	0.0352	29.066	1.126	0.0593	24.544	1.230	0.1031	19.732
1.034	0.0167	35.537	1.074	0.0357	28.952	1.128	0.0602	24.415	1.240	0.1071	19.401
1.035	0.0172	35.290	1.075	0.0361	28.839	1.130	0.0610	24.289	1.250	0.1111	19.085
1.036	0.0177	35.049	1.076	0.0366	28.728	1.132	0.0619	24.164	1.260	0.1150	18.783
1.037	0.0182	34.816	1.077	0.0371	28.619	1.134	0.0628	24.042	1.270	0.1189	18.493
1.038	0.0186	34.588	1.078	0.0375	28.511	1.136	0.0637	23.921	1.280	0.1228	18.216
1.039	0.0191	34.367	1.079	0.0380	28.405	1.138	0.0645	23.803	1.290	0.1266	17.949
1.040	0.0196	34.151	1.080	0.0385	28.299	1.140	0.0654	23.686	1.300	0.1304	17.692

LEGEND: VSWR Voltage Standing Wave Ratio   ρ Voltage Reflection Coefficient   RL(dB) Return Loss in dB

Table 4.5-3 VSWR and Related Parameters

VSWR	ρ	RL(dB)
1.310	0.1342	17.445
1.320	0.1379	17.207
1.330	0.1416	16.977
1.340	0.1453	16.755
1.350	0.1489	16.540
1.360	0.1525	16.332
1.370	0.1561	16.131
1.380	0.1597	15.936
1.390	0.1632	15.747
1.400	0.1667	15.563
1.410	0.1701	15.385
1.420	0.1736	15.211
1.430	0.1770	15.043
1.440	0.1803	14.879
1.450	0.1837	14.719
1.460	0.1870	14.564
1.470	0.1903	14.412
1.480	0.1935	14.264
1.490	0.1968	14.120
1.500	0.2000	13.979
1.520	0.2063	13.708
1.540	0.2126	13.449
1.560	0.2188	13.201
1.580	0.2248	12.964
1.600	0.2308	12.736
1.620	0.2366	12.518
1.640	0.2424	12.308
1.660	0.2481	12.107
1.680	0.2537	11.913
1.700	0.2593	11.725
1.720	0.2647	11.545
1.740	0.2701	11.370
1.760	0.2754	11.202
1.780	0.2806	11.039
1.800	0.2857	10.881
1.820	0.2908	10.729
1.840	0.2958	10.581
1.860	0.3007	10.437
1.880	0.3056	10.298
1.900	0.3103	10.163

VSWR	ρ	RL(dB)
1.920	0.3151	10.032
1.940	0.3197	9.904
1.960	0.3243	9.780
1.980	0.3289	9.660
2.000	0.3333	9.542
2.100	0.3548	8.999
2.200	0.3750	8.519
2.300	0.3939	8.091
2.400	0.4118	7.707
2.500	0.4286	7.360
2.600	0.4444	7.044
2.700	0.4595	6.755
2.800	0.4737	6.490
2.900	0.4872	6.246
3.000	0.5000	6.021
3.100	0.5122	5.811
3.200	0.5238	5.617
3.300	0.5349	5.435
3.400	0.5455	5.265
3.500	0.5556	5.105
3.600	0.5652	4.956
3.700	0.5745	4.815
3.800	0.5833	4.682
3.900	0.5918	4.556
4.000	0.6000	4.437
4.100	0.6078	4.324
4.200	0.6154	4.217
4.300	0.6226	4.115
4.400	0.6296	4.018
4.500	0.6364	3.926
4.600	0.6429	3.838
4.700	0.6491	3.753
4.800	0.6552	3.673
4.900	0.6610	3.596
5.000	0.6667	3.522
5.200	0.6774	3.383
5.400	0.6875	3.255
5.600	0.6970	3.136
5.800	0.7059	3.025
6.000	0.7143	2.923

VSWR	ρ	RL(dB)
6.200	0.7222	2.827
6.400	0.7297	2.737
6.600	0.7368	2.653
6.800	0.7436	2.573
7.000	0.7500	2.499
7.200	0.7561	2.428
7.400	0.7619	2.362
7.600	0.7674	2.299
7.800	0.7727	2.239
8.000	0.7778	2.183
8.200	0.7826	2.129
8.400	0.7872	2.078
8.600	0.7917	2.029
8.800	0.7959	1.983
9.000	0.8000	1.938
9.200	0.8039	1.896
9.400	0.8077	1.855
9.600	0.8113	1.816
9.800	0.8148	1.779
10.000	0.8182	1.743
11.000	0.8333	1.584
12.000	0.8462	1.451
13.000	0.8571	1.339
14.000	0.8667	1.243
15.000	0.8750	1.160
16.000	0.8824	1.087
17.000	0.8889	1.023
18.000	0.8947	0.966
19.000	0.9000	0.915
20.000	0.9048	0.869
22.000	0.9130	0.790
24.000	0.9200	0.724
26.000	0.9259	0.668
28.000	0.9310	0.621
30.000	0.9355	0.579

VSWR	ρ	RL(dB)
32.000	0.9394	0.543
34.000	0.9429	0.511
36.000	0.9459	0.483
38.000	0.9487	0.457
40.000	0.9512	0.434
42.000	0.9535	0.414
44.000	0.9556	0.395
46.000	0.9574	0.378
48.000	0.9592	0.362
50.000	0.9608	0.347
55.000	0.9643	0.316
60.000	0.9672	0.290
65.000	0.9697	0.267
70.000	0.9718	0.248
75.000	0.9737	0.232
80.000	0.9753	0.217
85.000	0.9767	0.204
90.000	0.9780	0.193
95.000	0.9792	0.183
100.000	0.9802	0.174

Table 4.5-3 Continued

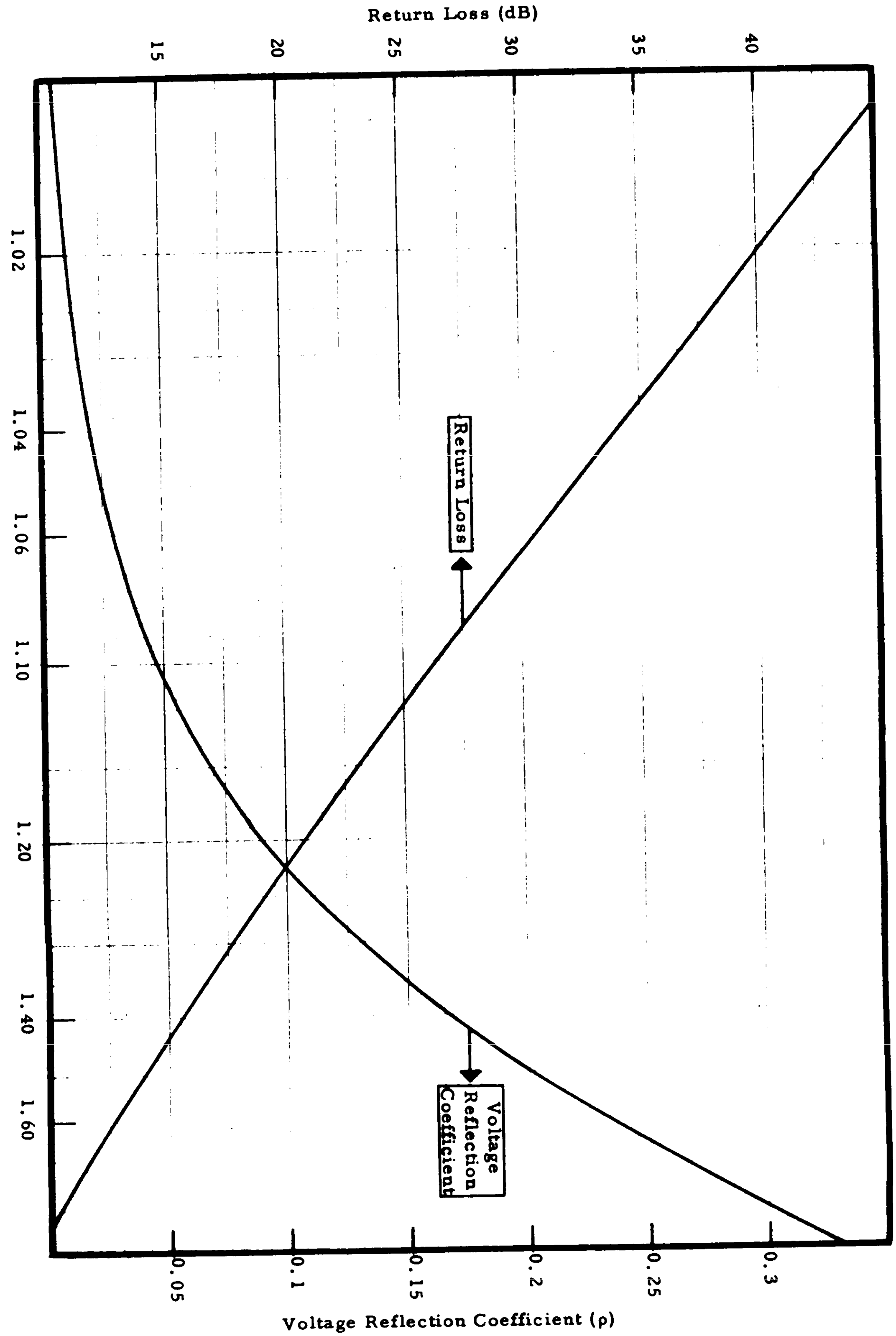


Figure 4.5-20 VSWR and Related Parameters

must be corrected for the ratio of baseband to voice channel bandwidth and for the RMS load factor. In equation form, the voice channel signal to feeder echo noise ratio becomes:

$$S/N_f = S/D + \log\frac{B_b}{b_c} - LF \text{ dB} \qquad (4.5\text{-}8)$$

The conversion to flat-weighted noise is as follows:

$$N_f = \text{antilog}\ \frac{90 - S/N_f}{10}\ \text{pWO}.$$

The foregoing feeder echo noise calculations are performed separately for each end of a hop by arbitrarily designating one end the transmitter and the other end the receiver. At the conclusion, these two noise results are summed together to give a total hop feeder echo noise contribution.

4.5.22 Time-invariant nonlinear noise

4.5.22.1 The sum of the total feeder echo noise and equipment intermodulation noise in this design will be called the time invariant nonlinear noise since these noise components do not depend on path loss variability. This total noise component is normally the dominant contribution for relatively high signal levels near the long -term median. For this case, an approximation may be made in the long -term noise calculations by omitting the smaller thermal noise contribution which will be discussed in the following paragraph. Conversely, the time-invariant nonlinear noise may be dropped for approximating short-term noise calculation at low signal levels near FM threshold since the thermal noise contribution will now be the dominant factor.

4.5.23 Thermal noise

4.5.23.1 As a natural law, thermal noise is always present. Its power depends on the absolute temperature of the point where it is measured, and also on the bandwidth. The thermal noise power per Hz bandwidth at the radio-relay receiver input is given by the expression kT_o. At an ambient temperature of 27° C (300° K) this is 4 x 10^{-21} W/Hz which corresponds to a power level of -174 dBm/ Hz. It can be seen directly from the expression given, that the thermal noise power of the point considered can be reduced by cooling this point. Very low temperatures are required to get a remarkable improvement in thermal noise. This is very expensive and, therefore, not used on terrestrial radio-relay systems. In addition, the noise power seen by antennas pointed at low elevation angles is about -174 dBm/Hz making very little improvement possible by cooling the receiver input impedance.

4.5.23.2 The thermal noise power measured at the receiver output s hews a higher value than one would expect from the thermal noise of the input alone. The difference between both these values is the thermal noise power produced in the receiver itself. By special measures it can be kept small. But some of these measures are very expensive, because they are also using the cooling of equipment to very low temperatures. Normal radio-relay systems must be economical in use, and for this reason it is unwise to employ expensive methods only to get a few dB of improvement.

4.5.23.3 The thermal noise characteristics of the receiver which add to the input thermal noise are expressed by the “receiver noise figure” in dB which is the ratio of the thermal noise measured at the receiver output to the thermal noise expected at the same point if only the ambient noise given by kT_o is present at the receiver input. Because of the reasons mentioned above, most practical microwave systems have receiver noise figures of about 10 dB.

4.5.23.4 In the frequency bands of interest here the thermal noise power per Hz bandwidth is constant. The total thermal noise power of a receiver is therefore directly proportional to the bandwidth of the receiver.

4.5.23.5 Thermal noise has random characteristics with substantial fluctuations relative to its mean power so that even very high peaks can occur with a small probability.

4.5.24 Points at which thermal noise power can influence the signal

4.5.24.1 It has already been mentioned that the thermal noise can influence the useful signal at the receiver input where the useful signal is at a very low level. But also within the receiver there are several points with low signal levels where thermal noise is added and can therefore contribute to the total thermal noise of the receiver such as the inputs of amplifiers. These points do not contribute a significant amount of thermal noise in well designed systems.

4.5.25 The mechanism by which the thermal noise power can influence the signal

4.5.25.1 Thermal noise signal can be assumed to be voltage vector with varying amplitude and phase which is added to the useful signal represented by a frequency modulated carrier of constant amplitude. The vector resulting from the addition of the noise vector and the carrier vector is then a vector with both amplitude and phase varying. Within the receiver this signal passes an amplitude limiter so that its amplitude is made constant again, but its phase is still disturbed.

4.5.26 Pre-emphasis

4.5.26.1 After demodulation, thermal noise power increases with baseband frequency so that the higher channels have smaller signal-to-thermal-noise ratios than the lower ones. To compensate for this effect in most radio-relay systems, pre-emphasis is applied. This means that before frequency modulation is accomplished in the transmitter the level of the upper part of the baseband is increased while the level of the lower part is decreased. This is done in a manner so that the mean power in the baseband is the same with or without pre-emphasis. Therefore, the C. C. I. R. in its Recommendation 275 [81] has standardized frequency characteristic of pre-emphasis for all types of broadband systems. Between the lowest and the highest telephone channel this pre-emphasis value is 8 dB, and the mean pre-emphasis improvement Ip = 4dB.

4.5.27 Calculate long-term median thermal noise

4.5.27.1 For purposes of system noise calculations, thermal noise is defined as noise from all sources in a channel when there is no modulated signal present on any of the channels in the microwave system. By this definition, thermal noise includes atmospheric and cosmic noise, and all intrinsic and thermal noise produced in the equipment when no modulation is present. Thermal noise is measured in a channel with all modulation removed from all channels of the systerm.

4.5.27.2 The signal-to-thermal noise ratio in an FDM-FM system is related to path loss variability. As the path loss on a hop becomes low; i. e. , the received signal level becomes high, the thermal noise is quite low and as received signal level decreases toward FM threshold, the thermal noise becomes proportionally higher. Signal-to-thermal noise ratio, S/N_t, in a voice channel is proportional to received signal level P_r or carrier-to-noise ratio C/N in the region above FM threshold (usually taken as 10 db above thermal noise threshold). It may be expressed in several forms for this region, as follows:

$$S/N_t = P_r + 20 \log \frac{\delta f}{f_m} - 10 \log kTb_c - F \qquad (4.5\text{-}10)$$

$$S/N_t = P_r + 20 \log \frac{\Delta F}{f_m} - PF - LF - 10 \log kTb_c - F \qquad (4.5\text{-}11)$$

$$S/N_t = C/N + 20 \log \frac{\Delta F}{f_m} - PF - LF + 10 \log \frac{B_{IF}}{b_c} \quad (4.5\text{-}12)$$

$$S/N_t = C/N + 20 \log \frac{\delta f}{f_m} + 10 \log \frac{B_{IF}}{b_c} \quad (4.5\text{-}13)$$

where $$\Delta F = (\delta f)\,(\text{antilog } \frac{PF}{20})\,(\text{antilog } \frac{LF}{20}) \text{ in kHz} \quad (4.5\text{-}14)$$

and $$LF = -10 + 10 \log n \text{ in dB} \quad (4.5\text{-}15)$$

Δ] F is the peak carrier deviation in kHz

δf is the rms per channel deviation in kHz

S/N_t is the voice channel signal to thermal noise ratio in dB

P_r is the received carrier level in dBm,

C/N is the predetection carrier-to-noise ratio in dB and N is the receiver front end thermal noise power in the same units as P_r

PF is the baseband signal peak factor of 13.5 dB

LF is the RMS noise load factor in dB

b_c is the useable voice channel bandwidth taken to be 3.100 in kHz

B_{IF} is the receiver IF bandwidth in kHz

f_m is the highest modulating frequency in the baseband in kHz

F is the receiver noise figure in dB

k is Boltzman's constant, 1.3804×10^{-20} millijoules/°K, and

T is the antenna temperature taken to be 290°K.

n is the number of voice channels in the baseband.

4.5.27.3 The terms on the right hand side of the first two equations with the exception of P_r may be calculated for a given set of equipment parameters. This then becomes a constant - a figure of merit - and as P_r is allowed to vary the vo0ice channel signal-to-thermal-noise ratio varies in proportion. Using this information, a receiver transfer characteristic or "quieting curve" similar to those in figures 4.5-16 and 4.5-17 may be constructed, where its slope is uniquely determined by any of the above equations for conditions above FM threshold.

4.5.27.4 The quieting curve is a good indication of the link dynamic performance characteristics. It is essentially a plot of voice channel signal-to-noise ratio versus received signal level. For a graph that is linear in decibels such as worksheet 4.5-10, the main portion of the quieting curve is a straight line with unity slope in accordance with the equations in paragraph 4.5.27.2. This portion is limited at the upper end (high received signal levels) by the equipment intermodulation noise, and at the lower end by the FM improvement threshold where the linear relationships of equations (4.5-10, -11, -12, and -13) no longer hold.

4.5.27.5 A good approximation to the quieting curve can be constructed in the following manner on worksheet 4.5-10 using information from the preceding worksheets:

a. Determine received signal level for which the signal-to-thermal noise ratio equals zero (from step 7.6 on worksheet 4.5-7), increase this value by 20 dB, and plot this point on the graph at the 20 dB ordinate value.

b. Draw a straight line with unity slope through this point.

c. Mark on this line the point corresponding to the FM improvement threshold (step 4.15 on worksheet 4.5-4) as abscissa value.

d. Draw a horizontal line at the ordinate corresponding to the signal-to-equipment intermodulation noise ratio S/N_e (from step 7.2 on worksheet 4.5-7).

e. The available dynamic range for linear system performance is that portion of the unity - slope straight line between the FM improvement threshold and the line intersection with the S/N_e line from (d.) above.

f. Performance below the FM improvement threshold can be approximated by a line with a slope of 4 (4 dB decrease in signal-to-noise ratio for each 1 dB decrease in received signal level) at S/N values lower than that corresponding to the FM improvement threshold.

4.5.27.6 The completed worksheet 4.5-10 in section 4.5.41 provides an example of a quieting curve. Transitions between the three straight -line portions of the curve can be made by rounding as shown.

4.5.28 Determine long -term median total noise performance

4.5.28.1 The preceding sections have shown the calculations of all noise contributions from several sources. The median noise for each hop is the sum of the thermal noise calculated for the long term median and the time - invariant equipment and intermodulation noise.

4.5.29 Compare hop predicted noise with noise allowance

4.5.29.1 The next step is to compare the calculated long -term median total noise with the noise allowance which was determined in Section 4.5.16 and entered on worksheet 4.5-3. The calculated noise should be compared with the per -hop estimated total noise rather than the allocated per-hop noise. If the calculated noise is only slightly larger than this estimate, no readjustment should be made at this point unless the estimated system noise is nearly equal to or greater than the total system allocation. Other links may be more favorable than the estimate and the link design may be adequate.

4.5,30 Adjust hop/equipment requirements

4.5.30.1 When a calculation shows that a hop will not meet the median estimated noise requirement the sources of noise should be checked to see which one or ones exceed those estimated on worksheet 4.5-3.

4.5.30.2 It becomes at this point a matter of evaluating the cost of the necessary improvements. For instance, if more transmitter power is required, the cost of the power amplifier must be balanced against the requirement, Such decisions may need to be deferred to a higher authority.

4.5.31 Estimate short-term signal levels at the receiver input

4.5.31.1 The purpose of this section is to check the adequacy of the equipment parameters to meet the short-term time availability requirements which correspond to total voice channel noise power less than. 1,000,000 pWO during 99.9995% of the year. This time availability y corresponds to an allowable outage time of about 2 minutes per year, and requires a large fade margin. Its magnitude can be estimated usually from two causes of signal fading, namely rain attenuation and multipath propagation. These effects were discussed in sections 4.2.24 and 4.2.27 respectively. In general, these two effects will not occur simultaneously since heavy rain will break up any atmospheric stratification responsible for multipath and conversely, during periods of considerable atmospheric stratification, rains heavy enough to cause much attenuation are very unlikely.

4.5.32 Rain attenuation

4.5.32.1 Since rain attenuation can not usually be alleviated by diversity operations, one must evaluate the percentage of time the radio hop attenuation is likely to cause the voice channel noise to exceed 1,000,000 pWO.

4.5.32.2 The first step is to determine the applicable rainfall zone from the maps in Section 4.2.24. To continue with the example of Hop H, assume that it is in Rainfall Zone 3. From the calculations in Section 4.5.18 there is a 48.8 dB fade margin available using 600 voice channels with 200 kHz per-channel deviation. In Section 4.5.19 we considered using an RF preamplifier to increase system gain and reduce the receiver noise figure, in this case from 10 dB to about 6 dB. This will provide a fade margin increase of 4 dB to 52.8 dB.

4.5.32.3 A fade margin of 52.8 dB can be pro-rated to 5.28 dB/km for a 10 km rain cell diameter (as discussed in Section 4.2.24).

For the example, figure 4.2-12b (Rain Zone 3) is used to estimate the percent of time for which the attenuation over the link will exceed this value by entering 5.28 dB/km as the ordinate and determining the corresponding abscissa value for the (approximately) 8.2 GHz carrier frequency. In this case thie involves visual interpolation between the curves for 7 and 10 GHz. The result is the percentage of time during which the 52.8 dB fade margin, pro-rares as described above, will exceede. For the example, this is less than 0.0001% of the time, or less than 32 seconds per year.

5.4.33 Multipath Fading.

4.5.33.1 Equation 4.2-22 in Section 4.2.27 is used to calculate the percentage of time that multipath fading will cause voice channel noise to exceed 10^6 pWO. Appropriate values of the constants "a" and "b" based on the terrain and climate of the radio hop must be selected which is somewhat arbitrary and a matter of engineering judgement. For Rain Rate Zone 3 appropriate values might be a = 1 and b= 1/4. For a 43 km path length and 8.2 GHz carrier frequency, the fade margin is exceeded during a fraction of 5.1×10^{-7} of the year or 0.000051% outage time.

4.5.33.2 To evaluate the total hop outage per year, the outage times due to rain attenuation and multipath are summed and the total compared with the desired value of 0.0005%. For the example the total estimated outage time will be less than 0.000151%. This is an indication that the link design is adequate.

4.5.33.3 If, for some hop, the estimated total outage time exceeds the allocated time of 2 minutes per year, fade margin is not sufficient and will have to be increased if the reliability requirements must be met. The methods for increasing fade margin, such as improving noise figures, increasing antenna size and increasing transmitter power are expensive, but can be evaluated in terms of cost versus increased reliability. Before such methods are considered, we should evaluate potential improvement by diversity operation.

4.5.34 Diversity

4.5.34.1 If a particular hop will not meet the time availability requirement, the advantages of diversity reception may be considered since at least fading depth due to multipath can be substantially reduced as shown in figure 4.5-21 for dual space diversity. This figure is based on the improvements shown in [82] out to the point corresponding to 99.99% of the time reliability (0.01% outage time). Extension of the curves in figure 4.5-21 are straight -line extrapolations as a first approximation. The fade depth for any fraction of the year given by the abscissa will be reduced by the amount of diversity improvement read on the corresponding ordinate for the applicable type of combiner. Thus, at 0.0005%, a diversity gain of about 26 dB is expected for selection combining which will reduce the required fade margin by the same amount. Figure 4.5-22 shows the effect of such an improvement on the example hop, and worksheet 4.5-11 is provided as an aid in preparing similar graphs for specific links under study. The relations between percentages of time and fade margin in dB are approximated by straight lines in order to facilitate extrapolations beyond the scale provided. One may select two convenient values of the fade margin, M_f, calculate the corresponding percentages P_{mft} using the step-by-step procedures in worksheet 4.5-8, plot the points on worksheet 4.5-11, and draw a straight line through these points. Useful values of M_f will usually be between 10 and 20 dB and 30 and 40 dB, respectively; the threshold value may of course be used for one of the values if it falls within the range of the graph. For the example discussed here, a fade margin of only 20 dB would be adequate to provide not more than 0.0001% of the year outage time if dual diversity is used. Median diversity improvement, Id, as entered in worksheet 4.5-4, can be estimated from [82] as approximately 2.5 dB for selection, 3.0 dB for equal gain, and 3. 5 dB for maximal ratio combiners.

4.5.34.2 Questions might arise why such large fade margins are designed into the hops if much smaller margins would suffice. One reason

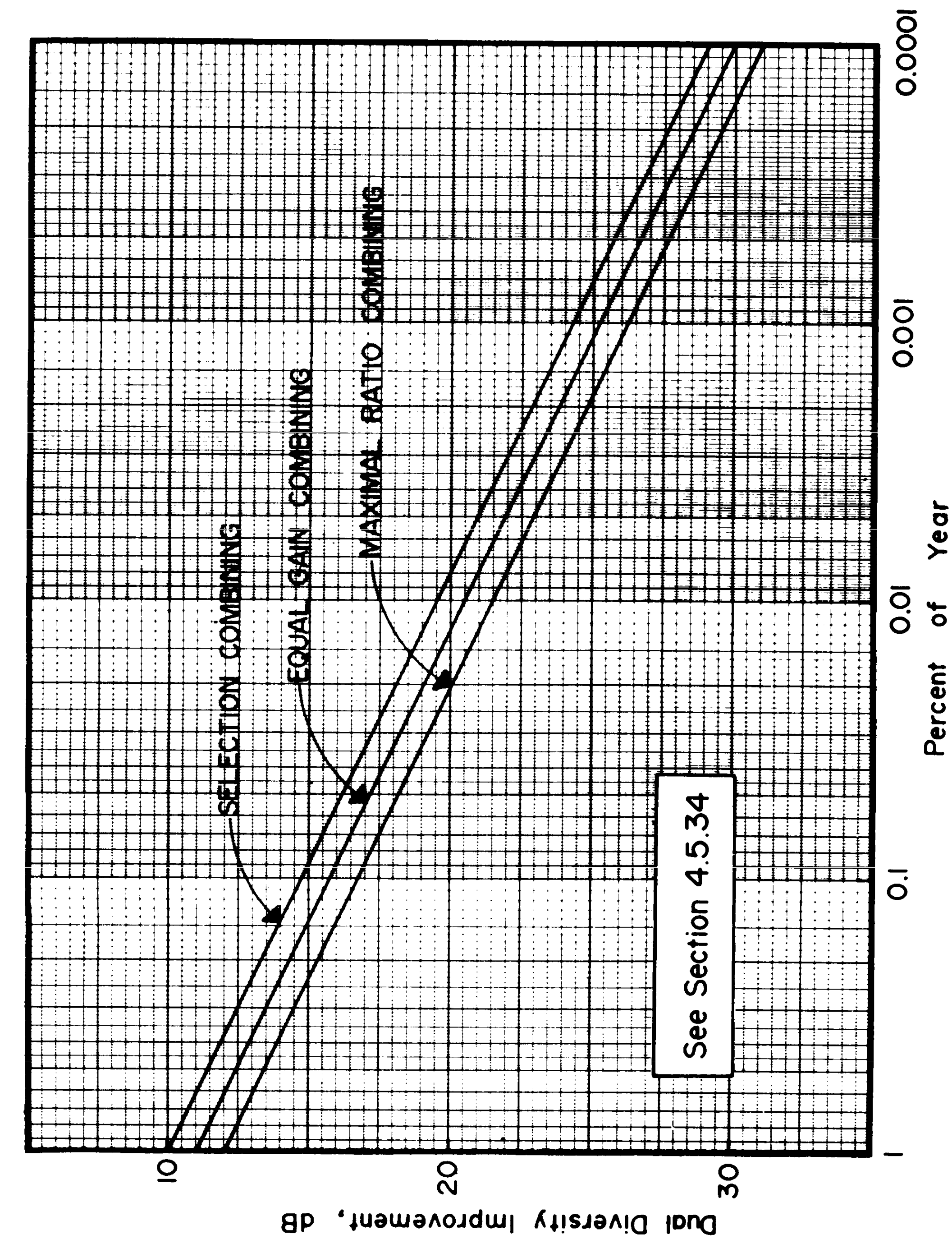


Figure 4.5-21 Diversity Improvement

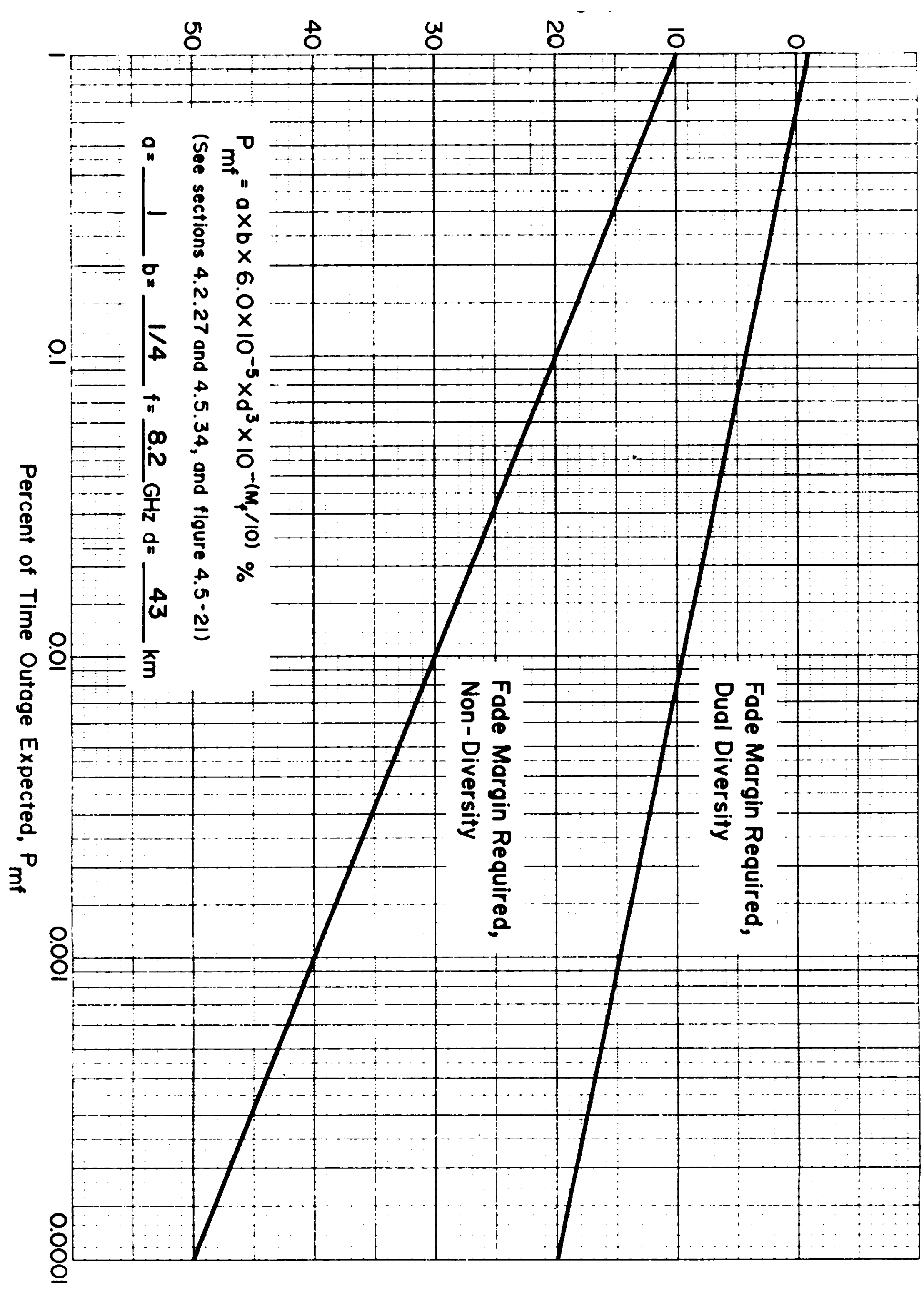


Figure 4.5-22. Path Improvement with Diversity.

is that the low median noise requirements usually will provide large fade margins. Another reason is that occasionally severe power fading will occur due to ducting or trapping, and diversity will not be effective. However, if a large fade margin has been designed into the system, there is a much better chance that the system will not have excessive noise during severe power fading.

4.5.34.3 Diversity combining techniques such as post-detection maximal ratio and linear addition may entail some risk for digital transmission because of unknown and varying differential time-of -arrival values. If the times of arrival of two like data streams are delayed relative to each other by more than approximately one quarter of a bit interval (on the order of nanoseconds for high-speed data), addition on a power or voltage basis may cause serious pulse distortion and give rise to error bursts. For this reason, a baseband switch that selects one or the other of the data streams is preferable although the switching function itself may introduce error bursts. However, provisions can be made to avoid unnecessary switching. Instead of letting a set differential in signal level actuate switching regardless of the absolute signal level in the two channels, the switch should be disabled until the signal level of one channel is reduced to values close to threshold; if then the level of the other channel is significantly higher, switching may proceed.

4.5.34.4 A further improvement to be made is clock averaging and bit coherence of the demodulated data stream so that switching will in essence be error-free. This and similar methods are denoted by the term “hit-less switching”.

4.5.34.5 Pre-detection diversity combiners for digital systems require devices to insure coherency of the radio frequency phase (similar to those for FDM/FM systems) in order to avoid loss of synchronization and excessive error bursts. Additionally, modulation coherency is also required and may be more difficult to achieve.

4.5.34.6 At this time there is little information available on the performance of various combining techniques for high-speed digital data; an extensive test program would be required to obtain useful quantitative information that can be applied to system de sign.

4.5.35 Complete system summary charts

4.5.35.1 The next step in the design is to enter the total median noise calculated for each radio hop on figure 4.5-15 and sum the median noise values. This is compared with the System Noise Allocation. If the calculated noise exceeds the allocation, the individual links should be checked with the idea of reducing median noise. This effort to reduce the noise will be a matter of the cost and feasibility of modifications as already stated.

4.5.35.2 If some of the hops are changed, a new set of design sheets should be prepared and labeled "Issue 2" to ensure that the latest applicable design will be used.

4.5.36 System reliability

4.5.36.1 Mathematical models used to make reliability calculations for systems and subsystems ignore common causes of system failures since they are usually based on reliability figures for random failure of individual components from historical data for similar components operating with load conditions similar to those expected in the system. In addition to such component failures, real system failures may also occur because of human error in design, manufacture, installation, operation, and maintenance. Although reliability calculations will usually not accurately predict the reliability of a microwave subsystem, they are useful because no subsystem is likely to work adequately if the computations indicate a lack of required reliability. System reliability may be estimated in three ways:

a. on the basis of the reliability of its components;

b. on the basis of statistics for similar systems; and

c. on the basis of the system's own past history.

Reliability estimates made on the basis of a microwave relay system' s own history are the most accurate. If proper use is made of such historical data, reliability can probably be increased since weaker elements of the system are known and may be improved.

4.5.36.2 None of the three methods listed above can be expected to adequately estimate the probability of failure of high-reliability systems due to catastrophic causes such as tornadoes, earthquakes, vandalism, or sabotage. Only route diveristy offers some protection against such outages.

4.5.37 Reliability calculations

4.5.37.1 The reliability R of a component or subsystem can be defined as the ratio of the time that the device is in service to the time that it is desired to be in service. R may be estimated as follows:

$$R = 1 - \frac{MTTR}{MTBF} \qquad (4.5\text{-}16)$$

MTTR is the "mean time to restore" and MTBF is the "mean time between failures". MTTR consists of the sum of time periods required to locate the faulty device, report the fault, transport a replacement, install the replacement, and the turn-on-time for bringing the system back into service. Some or all of these periods may be eliminated or drastically reduced by automatic sensing, switching, and reporting. For fully redundant devices, estimates of reliability must be made on the probability of more than one failure at the same time. For cases where only one additional device is available for instantaneous replacement, the redundant reliability, R_{red} mav be estimated from the equation

$$R_{red} = 1 - \frac{(MTTR)^2}{(MTBF)^2} \qquad (4.5\text{-}17)$$

4.5.38 A practical example of LOS system reliability

4.5.38.1 Empirical information on the reliability of major long-distance Canadian radio-relay systems for the period 1963 - 1968 inclusive is given in [81], pp 133 - 138. Figure 4.5-23 shows the percent reliability based on the 2500 km Canadian system. Note the reliability increase for successive years. The total interruption time given by the complement of the ordinate in 4.5-23 divided into its various components is shown in figure 4.5-24 and the distribution of the various outage causes noticeable changes as the system ages.

4.5.39 Causes of system outage

4.5.39.1 Listed below are some causes of system outage.

a. Interference from external sources.

b. Interference from internal system sources.

c. Signal fading over individual hops.

d. Equipment failure due to component or subsystem failures.

e. Equipment failure due to human error.

f. Equipment failure due to catastrophic events such as tornados and earthquakes.

g. Equipment failure due to vandalism or sabotage.

The true reliability estimate must be based on the probability of any of these events occurring and the probability of correcting the failure with in a given period of time. Only the system outage causes (c.) and (d.) seem amenable to analysis and only part of the probable system outage time due to signal fading can be analyzed effectively (para. 4.4.11.2).

4.5.40 Designing for reliability

4.5.40.1 Reliability estimates for the total system, if to be made, should be based on the most relevant available statistics on hop reliability. Such statistics should be from links using the same type of

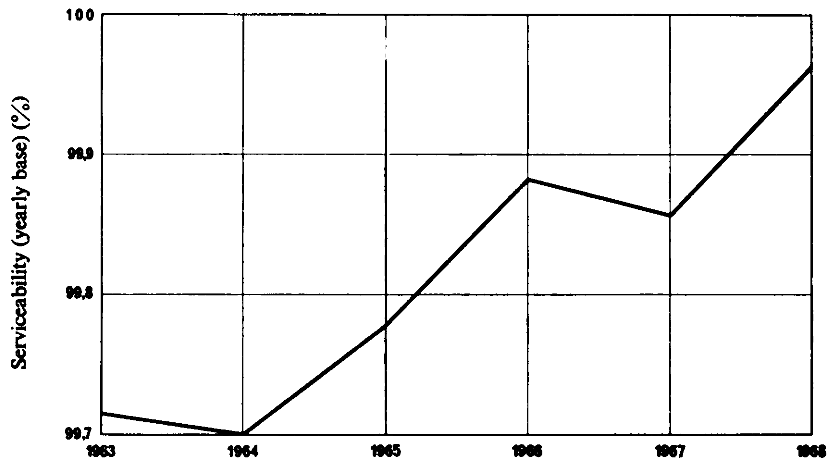


Figure 4.5-23 Operating reliability of the major Canadian radio-relay systems.

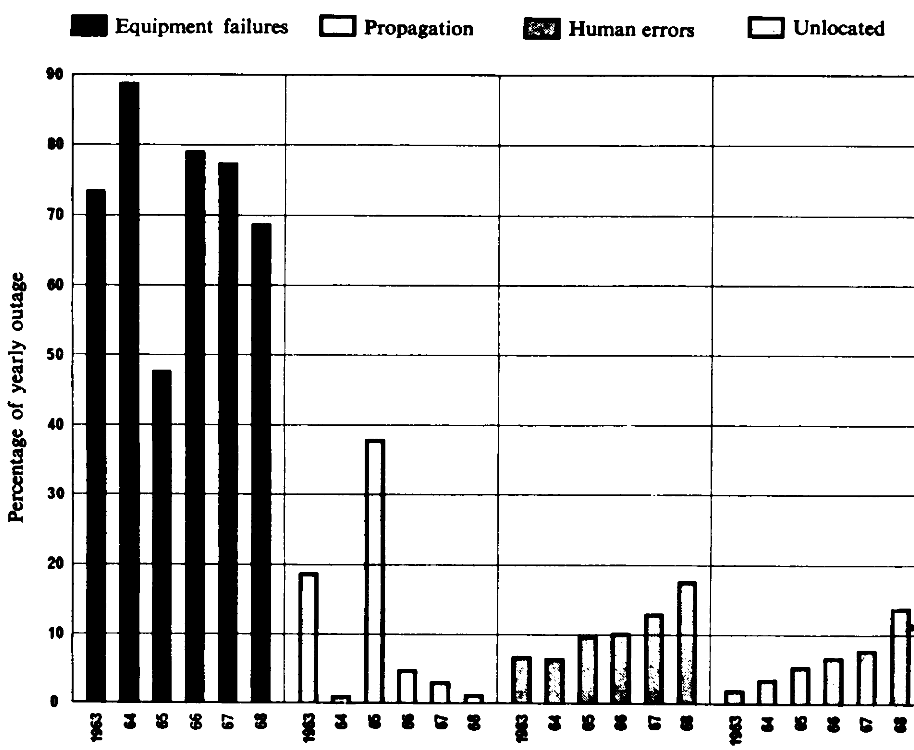


Figure 4.5-24 Sources of service failures in Canadian radio-relay systems shown as a percentage of yearly outage.

equipment and located in the same geographical area as the proposed systems. These data are not usually available. An additional problem in estimating system reliability is that hop reliability, even within the same system, is seldom very uniform. System reliability will usually be determined primarily by only one or a few hops, and as the system ages and corrective measures are taken, hop reliability values will change. Therefore, it is generally more useful to plan and design for high reliability than to try to estimate it.

4.5.40.2 Some general rules for reliability planning have been implied in previous sections and can be summarized as follows:

a. Avoid field installation procedures wherever possible such as field installation of RF cable or waveguide fittings.

b. Where field installation is required, specify an applicable military or industrial code or standard.

c. Give special consideration to the planning of the interfaces between subsystems especially where they must be procured from separate sources. Examples are between primary power and RF equipment, between antenna mounts and towers, between transmission lines and antennas, between test equipment and the communications equipment, and all waveguide connections.

d. Attempt to procure reliable subsystems by means of specification and testing.

e. Select reliable propagation paths.

f. Use redundancy wherever economically feasible.

g. Close the system into one or more loops if possible.

h. Provide for automatic fault sensing and reporting.

i. Provide a readily accessible inventory of spare modules and other system components.

j. Design for simplified maintenance by providing for module replacement in the field, with trouble shooting and repairs handled by manufacturers.

k. Provide adequate trained operations and maintenance manuals and training courses for personnel.

l. Design a system which permits as many subsystems as possible to be down for testing without interruption of service. Closed-loop systems can provide this feature.

m. Provide for adequate primary power reserves (fuel supply and battery reserve) at remote sites which may be isolated due to weather conditions for extended time periods.

4.5.41 Examples of Filled-in Worksheets

4.5.41.1 This section includes filled-in worksheets 4.4-4, 4.4-5, 4.5-4, 4.5-5, 4.5-6, 4.5-7, and 4.5-8. A single line-of-sight link approximately 50 km long is used as an example. Based on dual diversity with equal gain combining, an improved equipment noise power ratio (NPR) of 58 dB was assumed; on this basis, the link meets median noise objectives with 10 W transmitter power. Additional numbers in parentheses above the various entries correspond to 1 W transmitter power. In this case, the approximately 155 pWO noise objective for the 51 km path is not met.

Site Identification

(1) VOLMER (Name), NO. 1 (Abbreviation) (2) LYONS (Name), NO. 2 (Abbreviation)

Site Location and Physical Parameters

(3)	Latitude 36° 23' 20" N	(4)	Latitude 36° 37' 43" N	sec. 4.4.3
(5)	Longitude 120° 31' 20" W	(6)	Longitude 120° 01' 55" W	sec. 4.4.3
(7)	Altitude above mean sea level 402 m.	(8)	Altitude above mean sea level 523 m.	sec. 4.4.3
(9)	UTM Coord. 10SGF22242973	(10)	UTM Coord. 10SGF65415758	sec. 4.2.14
(11)	Azimuth to (2), 58° 32' 28" True	(12)	Azimuth to (1), 238° 49' 59" True	sec. 4.2.16
(13)	Proposed upper antenna height above (7), 100 m.	(14)	Proposed upper antenna height above (8), 100 m.	Worksheet 4.4-1
(15)	Proposed vertical diversity antenna separation from (13), 5 m.	(16)	Proposed vertical diversity antenna separation from (14), 5 m.	sec. 4.4.24
(17)	Proposed antenna type, PARABOLIC	(18)	Proposed antenna type, PARABOLIC	
(19)	Size 10 ft, 3.048 m	(20)	Size 10 ft, 3.048 m	fig. 4.4-33
(21)	Expected antenna gain 45.5 dB above isotropic	(22)	Expected antenna gain 45.5 dB above isotropic	fig. 4.4-30
(23)	Design center carrier frequency 8.0 GHz.	(24)	Receiver noise threshold $-174 + 10 \log B_{IF} + F$ −92.9 dBm.	par. 4.4.2.2

Worhsheet 4.4-4. Link Design Summary, Part 1
(Example)

(25) Required waveguide length, 110 m.	(26) Required waveguide length, 110 m.	worksheet 4.4-1 (for tower heights)
(27) Proposed waveguide type EW-71	(28) Proposed waveguide type EW-71	sec. 4.4.40
(29) Waveguide loss per standard length 2 dB per 30.5 m	(30) Waveguide loss per standard length 2 dB per 30.5 m	fig. 4.4-43
(31) Waveguide loss A_{tl} 7.2 dB (including connectors)	(32) Waveguide loss A_{tl} 7.2 db (including connectors)	fig. 4.4-43
(33) Circulator and/or Diplexer Losses A_c Transmit 1.0 dB	(34) Circulator and/or Diplexer Losses A_c Receive 1.0 dB	par. 4.4.43.1
(35) Isolator Losses A: Transmit — dB	(36) Isolator Losses A: Receive — dB	

(37) Net fixed losses, (31) + (32) + (33) + (34) + (35) + (36), 16.4 dB.

(38) Proposed transmitter power 10 (1) watts, +40 (+30) dBm. — sec. 4.4.44

(39) Path length 51.29 km. — worksheet 4.4-1

(40) Free space basic transmission loss, L_{bf}, 144.7 dB. — fig. 4.2-7 or (4.2-1)

(41) Atmospheric absorption, A_a, 0.8 dB. — fig. 4.2-8 & sec. 4.2.22

(42) Net loss, (37) + (40) + (41), 161.9 dB.

(43) Net gain (21) + (22) + (38) (dBm) 131.0 (121.0) dBm.

(44) Expected median receiver input power, P_r, (43) - (42) -30.9 (-40.9) dBm.

(45) Order of diversity used DUAL.

(46) Type of diversity combiner used EQUAL GAIN

(47) Rain rate zone 2. — fig. 4.2-11 or 4.2-13

Worksheet 4.4-5. Link Design Summary, Part 2
(Example)

4.1	Number of equivalent voice channels, n	300		sec. 4.1.3
4.2	Voice channel bandwidth, b_c	3100 Hz	(Usable bandwidth)	
4.3	Maximum modulating frequency, f_m	1300 kHz		table 4.5-2 (upper baseband limit)
4.4	Baseband bandwidth, B_b	1240 kHz	$B_b = f_m - f_\ell$, where f_ℓ is the lowest frequency in baseband	table 4.5-2
4.5	RMS load factor, LF	14.8 dBm0	-10 + 10 log n	step 4.1, par. 4.5.27.2
4.6	Numerical RMS load factor ℓf	5.48	antilog(LF/20)	step 4.5
4.7	Peak factor, PF	13.5 dB		par. 4.5.27.2
4.8	Numerical peak factor, pf	4.73	antilog(PF/20)	step 4.7
4.9	RMS per channel deviation, δf	200 kHz		par. 4.5.16.4 & table 4.5-2
4.10	RMS carrier deviation, δF	1096 kHz	δF = (ℓf)(δf)	step 4.6 & 4.9
4.11	Peak carrier deviation, ΔF	5181 kHz	ΔF = (pf)(ℓf)(δf)	steps 4.6, 4.8, & 4.9
4.12	Receiver IF bandwidth, B_{IF}	12,961 kHz	$B_{IF} = 2(\Delta F + f_m)$	steps 4.3 &4.11 table 4.5-2
4.13	Receiver noise figure, F	10.0 dB		par. 4.5.16.4 & 4.4.45.13
4.14	Receiver noise threshold	-92.9 dBm	-174 + 10 log B_{IF}(Hz) + F	steps 4.12, 4.13 or par. 4.5.27.2
4.15	FM improvement threshold	-82.9 dBm	-174 + 10 log B_{IF}(Hz) + F + 10	par. 4.5.27.2
4.16	Pre-emphasis improvement, I_p	4 dB		sec. 4.5.26
4.17	Median diversity improvement, I_d	3.0 dB		par. 4.5.34.1 worksheet 4.4-5, step (46)
4.18	Radio set NPR	58 dB		par. 4.5.20.3

Worksheet 4.5-4. Basic Parameters for Median Noise Calculations
(E x a m p l e)

5.1	Transmission line or waveguide length, transmitter	110 m		worksheet 4.4-4 & sec 4.5.19
	Type of transmission line or waveguide	EW-71		
5.2	Percent velocity of propagation	73 %v		fig. 4.5-18
5.3	Velocity of propagation, v	2.19×10^{8} m/sec	$v = (3 \times 10^{8})\ (\%v \times 10^{-2})$	par. 4.5.21.4
5.4	Echo delay time,	1.0×10^{-6} sec	$\tau = 2L/v$	par. 4.5.21.4
5.5	Radian delay	8.16 rad	$2\pi f_m \tau$	par. 4.5.21.4
5.6	Parameter A	0.843	$A = \delta F/f_m$	par. 4.5.21.4
5.7	S/D - r	+5.1 dB		fig. 4.5-19 par. 4.5.21.4
5.8	Transmit system			par. 4.5.21.5
	Antenna return loss	RL_{ANT} 26 dB		from applicable standards or manufacturer's specifications
	RF interface return loss	RL_{RFI} 32 dB		
5.9	Echo amplitude, r	72.4 dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$	par. 4.5.21.5 step 5.8, & step (31) from worksheet 4.4-5
5.10	Transmit signal-to-distortion ratio, S/D	77.5 dB	$S/D = (S/D - r) + r$	par. 4.5.21.8 step 5.7 & 5.9
5.11	Transmit signal-to-feeder echo noise, S/N_f	88.7 dB	$S/N_f = S/D + 10 \log \frac{B_b}{b_c} - LF$	par. 4.5.21.8
5.12	Transmit feeder echo noise, $N_{f(trans.)}$	1.35 pWO	$N_f = \text{antilog} \frac{90 - S/N_f}{10}$	par. 4.5.21.8

Worksheet 4.5-5. Transmitter Feeder Echo Noise Calculation
(Example)

6.1	Transmission line or waveguide length, receiver	110 m		worksheet 4.4-4 sec. 4.5.19
	Type of line or waveguide	EW-71		
6.2	Percent velocity of propagation	73 %v		fig. 4.5-18
6.3	Velocity of propagation, v	2.19×10^8 m/sec	$v = (3 \times 10^8)(\%v \times 10^{-2})$	par. 4.5.21.4
6.4	Echo delay time, τ	1.0×10^6 sec	$\tau = 2L/v$	par. 4.5.21.4
6.5	Radian delay	8.16 rad	$2\pi f_m \tau$	par. 4.5.21.4
6.6	Parameter A	0.843	$A = \delta F/f_m$	par. 4.5.21.4
6.7	S/D - r	+5.1 dB		fig. 4.5-19 par. 4.5.21.4
6.8	Receive system			par. 45..21.5
	Antenna return loss	RL_{ANT} 26 dB		from application standards or manufacturer's specifications
	RF interface return loss	RL_{RFI} 32 dB		
6.9	Echo amplitude, r	72.4 dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$	par. 4.5.21.5 step 6.8, & step (32) from worksheet 4.4-5
6.10	Receive signal-to-distortion ratio, S/D	77.5 dB	$S/D = (S/D - r) + r$	par. 4.5.21.8 step 6.7 & 6.9
6.11	Receive signal-to-feeder echo noise, S/N_f	88.7 dB	$S/N_f = S/D + 10 \log \frac{B_b}{b_c} - LF$	par. 4.5.21.8
6.12	Receive feeder echo noise, $N_{f(receive)}$	1.35 pWO	$N_f = \text{antilog} \frac{90 - S/N_f}{10}$	par. 4.5.21.8

Worksheet 4.5-6 Receiver Feeder Echo Noise Calculation
(Example)

7.1	Total feeder echo noise, N_f	2 7 pWO	$N_f = N_{f(trans)} + N_{f(receive)}$	step 5.12& 6.12
7.2	Signal/equipment intermodulation, S/N_e	69.2 dB	$S/N_e = NPR + 10 \log \frac{B_b}{b_c} - LF$	step 4.2, 4.4, 4.5, 4.18, & sec. 4.5.20
7.3	Equipment intermodulation noise, N_e	120 pWO	$N_e = \text{antilog} \frac{90 - S/N_e}{10}$	step 7.2, & par. 4.5.20.5
7.4	Calculate $20 \log \frac{\delta f}{f_m}$	-16.3 dB		step 4.3, & 4.9 & par. 4.5.27.2
7.5	Calculate $10 \log KTb_c + F$	-129.1 dBm	$-139.1 + F$	step 4.13, & par. 4.5.27.2
7.6	Signal-to-thermal noise ratio minus received signal level, $S/N_t - P_r$	112.8 dB	$S/N_t - P_r = -10 \log KTb_c - F + 20 \log (\delta f/f_m)$	step 7.4 & 7.5 & par. 4.5.27.2
7.7	Draw quieting curve on worksheet 4.5-10			par. 4.5.27.3
7.8	$P_r(0.5) = (P_r - 3\text{ dB})$	(-43.9) -33.9 dBm		par. 4.5.18.1 & worksheet 4.4-5
7.9	Median signal-to-thermal noise ratio, $S/N_t(0.5)$	(68.9) 78.9 dB	$(S/N_t - P_r) + P_r(0.5)$	step 7.6 & 7.8
7.10	Median thermal noise, $N_t(0.5)$	(129) 12.9 pWO	$N_t(0.5) = \text{antilog} \frac{90 - S/N_t(0.5)}{10}$	step 7.9
7.11	Emphasis-improved signal-to-thermal noise ratio, $S/N_{te}(0.5)$	(72.9) 82.9 dB	$S/N_{te}(0.5) = S/N_t(0.5) + I_p$	step 7.9 & 4.16
7.12	Emphasis-improved thermal noise, $N_{te}(0.5)$	(51) 5.1 pWO	$N_{te}(0.5) = \text{antilog} \frac{90 - S/N_{te}(0.5)}{10}$	step 7.11
7.13	Total median noise, $N_T(0.5)$	(173.7) 127.8 pWO	$N_T(0.5) = N_{te}(0.5) + N_f + N_e$	step 7.12,7.1 & 7.3

<u>Note:</u> Median values are denoted by (0.5).

Worksheet 4.5-7 Calculate Median Total Noise Performance
(Example)

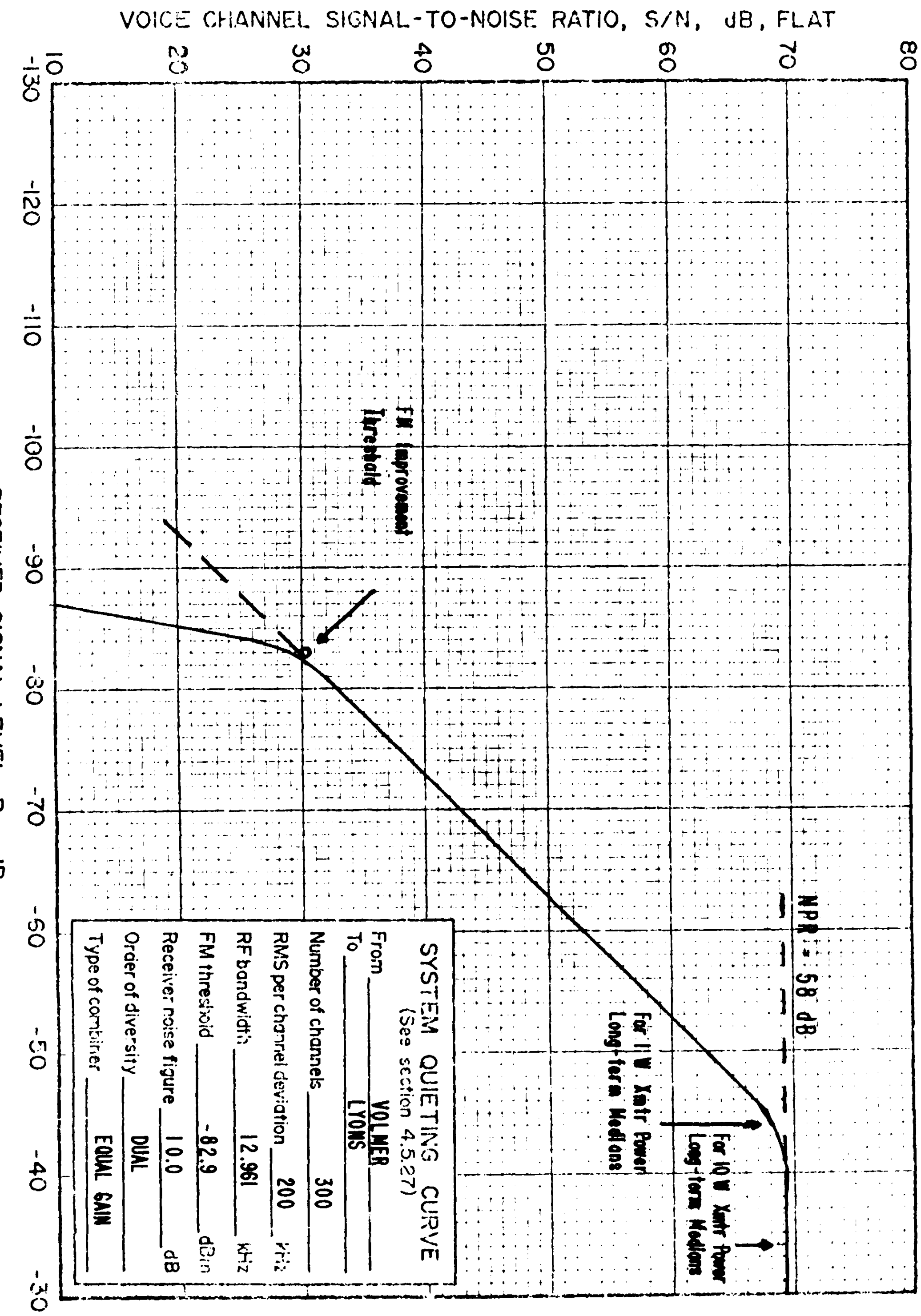
8.1	Fade margin, M_f	(38.4) 48.4 dB	$P_r(0.5)$-FM Imp. Thresh., or $P_r(0.5)-30+(S/N_t - P_r)$, whichever is smaller	step 4.15, 7.8 & 7.9 sec. 4.5.16
8.2	Percent time M_f is exceeded, P_{mf}	(0.0021%) 0.0021 %	$P_{mf} = 6\times10^{-5} a \times b \times f \times d^3 \times 10^{-(M_f/10)}$	sec. 4.2.27 & par. 4.5.33.1
8.3	Divide M_f by path length d or 10, whichever is less	4.9 dB/km		par. 4.2.24.2
8.4	Percent time fade margin is exceeded due to rain attenuation, P_{mfr}	<0.001 %	Enter value from step 8.3 as ordinate on graph of fig. 4.2-12 for the appropriate rain zone and read % time value of abscissa for carrier frequency, f	worksheet 4.4-3, step (23) worksheet 4.4-5, step (47) fig. 4.2-12 par. 4.5.32.3
8.5	Total percent time fade margin is exceeded, P_{mft}	(0.0021 %) 0.0021 %	$P_{mft} = P_{mf} + P_{mfr}$	step 8.2 & 8.4
8.6	Received signal level at FM threshold, P_{rTH}	-82.8 dBm	$P_r(0.5) - M_f$	step 7.8 & 8.1
8.7	Thermal signal-to-noise ratio at threshold, S/N_{tTH}	30.0 dB	$(S/N_t - P_r) + P_{rTH}$	step 7.6 & 8.6
8.8	Emphasis-improved, $S/N_{tTH}(E)$	34.0 dB	$S/N_{tTH} + I_p$	step 8.7 & 4.16
8.9	Emphasis-improved thermal noise at threshold, $N_{tTH}(E)$	398,110 pWO	anilog $\frac{90 - S/N_{tTH}(E)}{10}$	step 8.8
8.10	Total path-independent non-linear noise, N_{im}	122.7 pWO	$N_f + N_e$	step 7.1 & 7.3
8.11	Total emphasis-improved noise at FM threshold, $N_{TTH}(E)$	398,233 pWO	$N_{im} + N_{tTH}(E)$	step 8.9 & 8.10
8.12	Is total noise $N_{TTH}(E)$ ≤1,000,000 pWO and percent time P_{mft} less than 5×10^{-4}%	(no) yes (yes or no)		step 8.5 & 8.11

Worksheet 4.5-8. Calcuate Short-Term Noise Performance (Example)

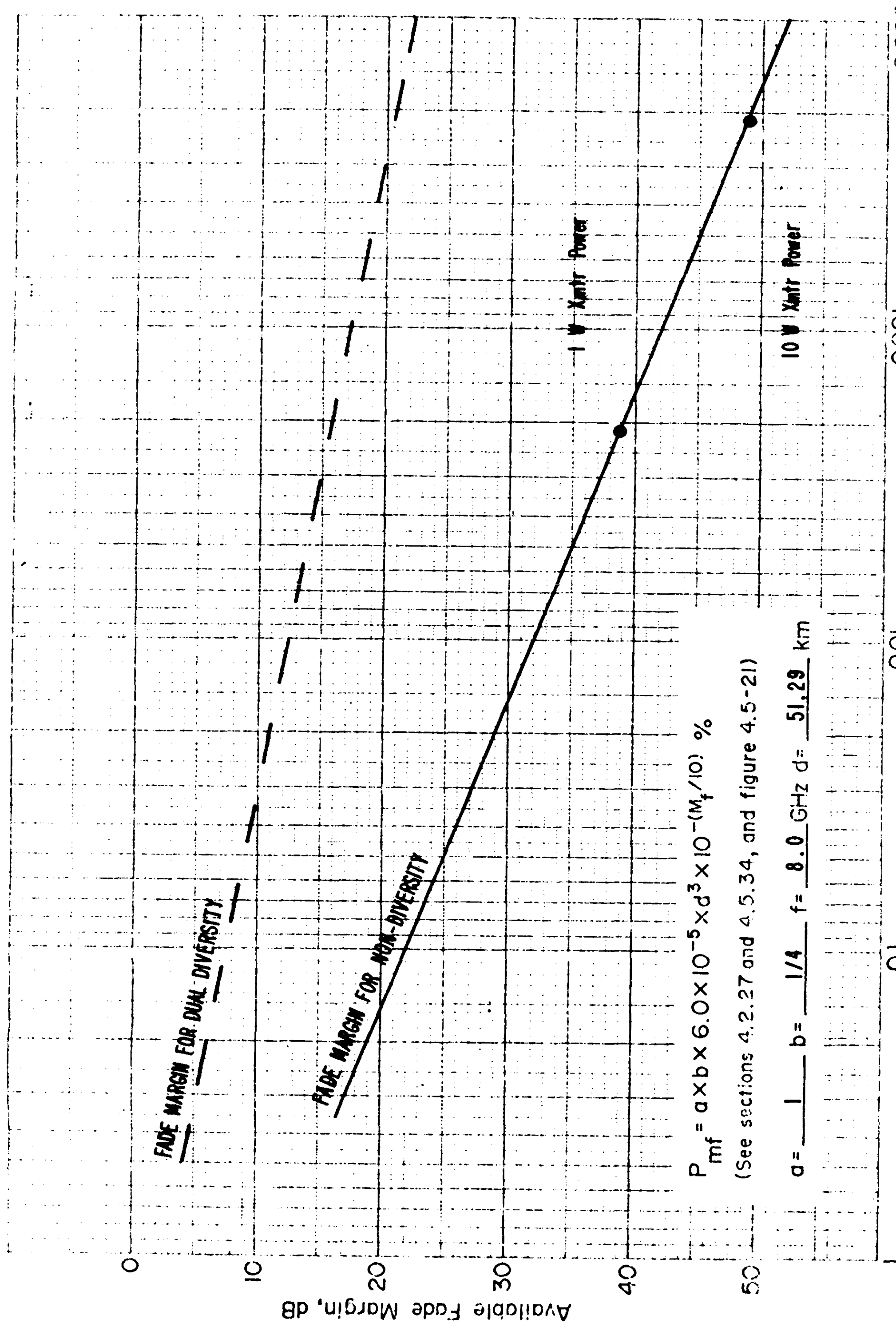
8.13 If "yes", and diversity was not selected previously, link design is completed. If "no", or diversity has already been selected, continue. If "no", and diversity was not selected previously, re-do steps 4.17, 4.18, and 7.2 through 8.12; then continue.

8.14	Plot line for non-diversity fade margin versus % of time on worksheet 4.5-11			par. 4.5.34.1 step 8.1 & 8.5
8.15	Read diversity improvement at percentage P_{mft} and other desired percentage values for type of combiner used	(23.7 I_d (0.0021%)) 28.5 I_d (0.0021%)		fig. 4.5-21 worksheet 4.4-4, step (46); & 8.5
8.16	Decrease fade margin values at P_{mft} and other desired percentage values by the appropriate I_d values	(45.2) 20.4 dB	(0.0021%) $M_f - I_d$ (0.0021 %)	step 8.14 & 8.15 par. 4.5.34.1
8.17	Plot line for diversity-improved fade margin versus % of time on worksheet 4.5-11			step 8.16 par. 4.5.34.1
8.18	Diversity and emphasis improved thermal signal-to-noise ratio $S/N_t(E,D)$ at P_{mft} percentage of time	(57.1) 62.5 dB	(0.0021%) $S/N_{tTH} + I_p + I_d$ (0.0021%)	step 8.8 & 8.15
8.19	Diversity and emphasis improved thermal noise $N_t(E,D)$ at P_{mft} percentage of time	(1950) 562 pWO	antilog $\frac{90 - S/N_t(E,D)}{10}$	step 8.18
8.20	Estimated total percent of outage time after diversity and emphasis improvement	<0.0021%	Read abscissa for diversity-improved fade margin line on worksheet 4.5-11 where it intersects the ordinate value for M_f	step 8.1 & 8.17
8.21	Total noise $N_T(E,D)$ at P_{mft} percentage of time	(2073) 685 pWO	$N_t(E,D) + N_{im}$	step 8.10 & 8.19
8.22	Is total noise ≤1,000,000 pWO	(yes) yes (yes or no)	If answers are no, adjust parameters and recalculate noise performance	
8.23	Is total outage time ≤5 x 10^{-4}%	(yes) yes (yes or no)		
8.24	If total noise cannot be reduced to ≤1,000,000 pWO, estimate percentage of time during which 1,000,000 pWO is exceeded	n/a %	Calculate ratio of total noise to 1,000,000 pWO, converted to dB, subtract from M_f, and read on the diversity improved line of worksheet 4.5-11 the percentage value corresponding to this ordinate	step 8.1 worksheet 4.5-11

Worksheet 4.5-8. Calculate Short-Term Noise Performance (continued)
(Example)



Worksheet 4.5-10. System Quieting Curve (Example)



Worksheet 4.5-11. Non-Diversity and Diversity Improved Fade Margins (Example)

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CHAPTER 5

FACILITY DESIGN

SECTION 5.0 INTRODUCTION,

5.0.1 In the previous chapters of this handbook, guidelines were provided to the design engineer for site selection, performance of surveys, and accomplishing the necessary calculations for path performance predictions. This chapter provides the facility design engineer with guidelines for arranging facilities and equipment on the selected site, developing installation specifications and instructions, and specifying hardware necessary for installation of the facility. The criteria contained in this chapter should be considered only as an illustration. Latest issues of applicable military standard should always be consulted for the definitive criteria that are in current use. Those responsible for recommending site selection and conducting site surveys for line-of-sight microwave communications stations should consult DCA Circular 370-160-3, Site Survey Data Book for Communications Facilities, November 19/1, including Supplement 3, Change 2, titled Line-of-Sight Station, dated July 1972.

SECTION 5.1 SITE PLANNING.

5.1.1 General.

5.1.1.1 This section is intended to contain information on all the usual aspects of planning a microwave communications station. Not everything discussed here will apply in every situation. The most extensive site planning is ordinarily done for an installation that will be new, a large communications hub, in an undeveloped area and utilized solely for microwave communications. If the microwave components are to be located at a new, multipurpose site, the microwave engineer need only provide his specialized requirement to the office directing overall planning. If an existing site (and structure) is to accommodate microwave communications, it will be necessary only to modify the site/building plan to include the addition of microwave equipment and plant. Once a particular site or location is chosen for a new microwave radio facility, specifications and instructions for preparation of the site must be generated. The content of the installation specifications must be such that a general contractor/ qualified Government personnel can accomplish the necessary site preparation, install the equipment and place it into operation. If the work is to be implemented by contractual actions, the specifications must comply with the appropriate procurement regulations in both format and content. In many cases the method of implementation is not known at the time the specifications are written; that is, whether the method of implementation will be contractual or organic. Therefore the specifications should generally be written so that they may be used in either case.

5.1.1.2 The bulk of the specifications will be in the form of drawings supplemented by written specifications. These specifications define those aspects of the work that can be adequately described in words or cannot be easily illustrated. The following areas of activity should be covered for total development and construction of a communications station:

a. Site layout and plot plan.

b. Access roads and parking areas.

c. Site preparation, clearing and grading (maximum slope of 5 percent)

d. Building design.

e. Water supply and sanitation systems.

f. Antenna footings and/or structures.

g. Prime and auxiliary power.

h. Heating, air conditioning and ventilating.

i. Site security fencing and lighting=

j. Real estate requirements.

5.1.1.3 Written specifications must be accurate, complete, and concise. They should define the extent of the work, specify the materials to be used, and establish responsibility for the performance of work. In some cases part of the work may be performed at more than one site by the same activity, whether Government or contractor. In these cases the written specifications may have general clauses applicable to all sites and specific clauses applicable to individual sites.

5.1.1.4 A set of installation specifications will be required for each microwave radio relay station. Individual site specifications will be influenced by the present requirements of the overall system and of the prospects for future expansion of the system. These requirements are derived from system plans and specifications.

5.1.1.5 The cost of future expansion can be reduced considerably by taking reasonable effort to ensure that: adequate space is available in the building or additional space can be made readily available; the power equipment is adequate for future needs; and the initial equipment is so located that rearrangement, rewiring, and modifications are reduced to a minimum.

5.1.1.6 Where new construction is planned for the exclusive use of the LOS communications facility, considerable thought should be given to the use of the same type and size of buildings at a number of sites with similar missions. Site adaptation of a basic definitive design is common practice in the design and construction business and this practice is often used by the U.S. Government.

5.1.2 Site Plan.

5.1.2.1 Development of site plans require close coordination of all aspects of civil and communications systems engineering to determine the optimum site configurations. The following factors should be considered when optimizing the site layout:

a. Site topography.

b. Available area.

c. Size, number, and types of buildings.

d. Direction and number of transmission paths.

e. Size, number, and height of antennas and supporting structures.

f. Projections or obstructions to radio paths.

5.1.2.2 The preparation of the site plan should be concurrent with the planning of the equipment building layout, since the orientation and location of the tower and equipment building may influence equipment layout design.

5.1.2.3 A typical site layout should concentrate on making the equipment building the center of site operations. The antenna structures should be placed as close to the equipment building as possible, consistent with design codes and standards to minimize the transmission line lengths required between equipment and antennas. Figure 5.1-1 is an example of a site layout.

5.1.2.4 The number and direction of transmission paths specified normally determine orientation of the equipment building with respect to the site and the tower. A power generator building may be used separately from the equipment building, but is located sufficiently close to minimize power cable voltage drops between generators and equipment. It usually requires less effort and cost to collocate the power generators/equipment in

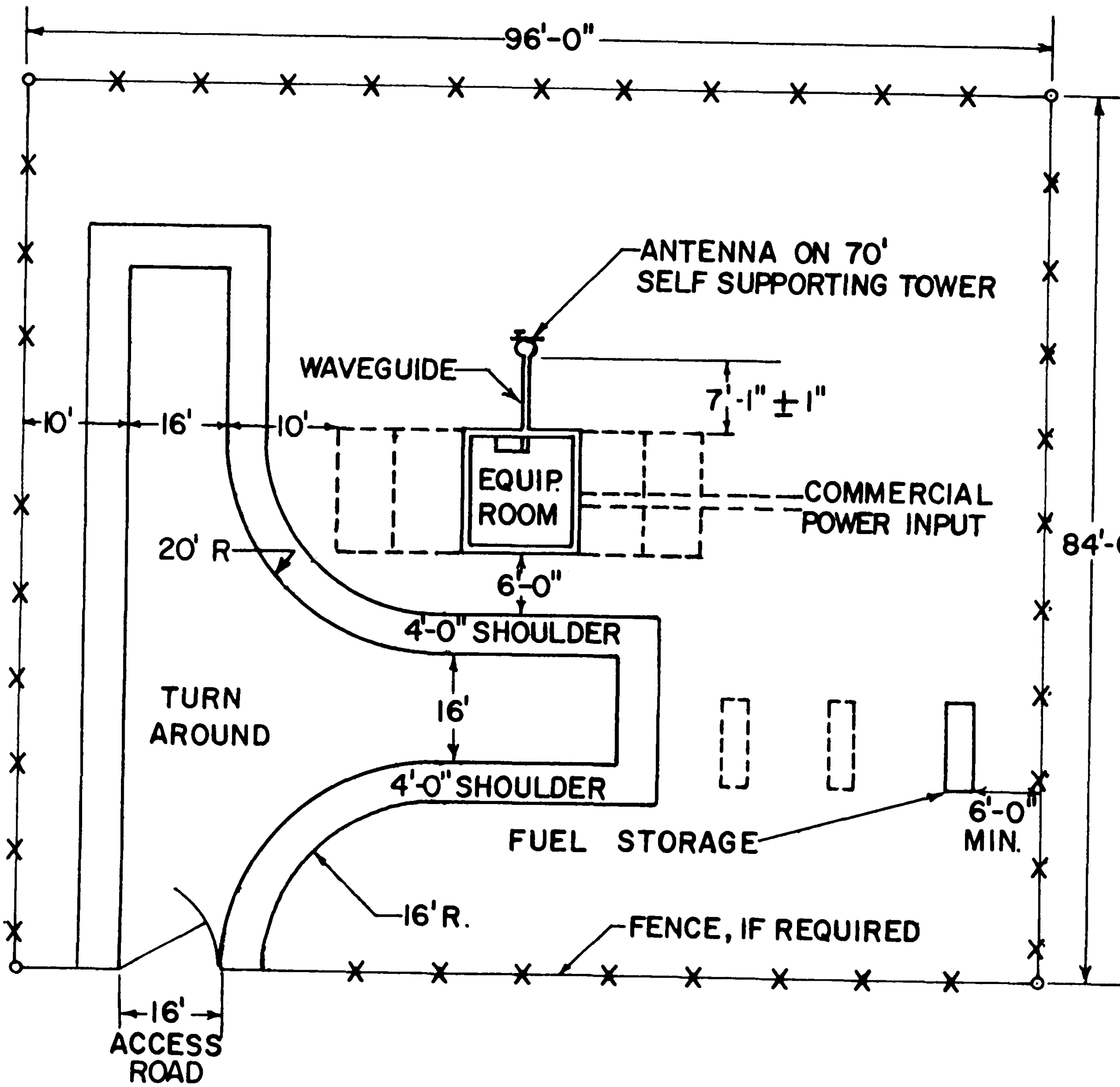

Figure 5.1-1 Typical Site Plan

the same building with the electronics equipment; in this case the building should have a specially designed room for generators to minimize noise and vibration and any hazards such as toxic fumes and fire. Ordinarily, a generator is secured to the floor through vibration mounts. The engine exhaust pipe to the outside is quieted by a muffler placed close to the engine. Fuel storage areas should be located where the peak RF power density is less than 5.0 watts per square centimeter, In those cases where it is necessary for the personnel to live on site, every effort should be made to provide as much isolation as possible between the living area and the work area. In many cases, physical isolation alone is not sufficient for health and safety of personnel; therefore, if required, sound absorption material should be installed on walls separating work and living areas. In the case of a small installation this may have to be accomplished in the same building; while, with a large installation it would be preferable to have separate buildings.

5.1.2.5 The topography of the site area often has an important effect upon the site layout. When necessary, compromises in site layout are effected to keep site preparation and grading within reasonable limits.

5.1.2.6 If the microwave station being planned requires attendant personnel, it will be necessary to locate water for their use. An adequate supply of safe water for domestic use and fire protection must be available at all times. Domestic water requirements at an installation include drinking, cooking, washing, bathing, sewage disposal, and possibly a small amount for watering cultivated areas. Most repeater sites do not require or justify elaborate systems and can be supplied by water trailer, community water main, etc. Terminal sites will usually be located in proximity to major compounds and can be supplied by the existing system.

5.1.2.7 The final site plan should show:

a. Site boundary and property lines.

b. Location and dimensions of buildings, tower, foundations fuel tanks, driveways, walks, retaining walls, drainage structures, water supply and sewage disposal (if required), fencing, access roads and parking areas.

c. Baseline and bench marks.

d. Elevations, azimuths, and coordinates for the center of each antenna.

e. Underground utilities.

f. Underground services.

g. Existing buildings facilities and roads.

h. Magnetic North direction/orientation.

i. A vicinity map.

5.1.2.8 Developing a site plan is the responsibility of the civil engineering authority based upon the communications system requirements as follows:

a. Where services and consequently facilities are required.

b. Type and volume of equipment space determined by amount and kind of equipment and physical support required.

c. The degree of operation and maintenance required governing personnel requirements.

d. Environmental and power requirements.

e. Location and alignment of antennas.

The LOS communications engineer has the responsibility of gathering this data and translating it into requirements civil engineering can use in preparing the site plan. For existing facilities a site plan should already exist and should be revised to show new construction. When the project involves the installation of equipment inside an existing, properly identified building, it should not be necessary to include a site plan with the engineering specifications.

5.103 Access Roads.

5.1.3.1 A preliminary engineering study, prior to the development of all weather site access roads and parking areas, should take into account vehicular traffic demands. Although the final access road position will depend primarily on site location, layout, and topography, the final design should offer direct routing, adequate right of way visability, good foundation, proper drainage, and degrees of curvature and grade consistent with good highway engineering practice.

5.1.4 Site Preparation.

5.1.4.1 The written specifications should include instructions concerning the clearing of the site and the extent of excavation, backfilling, and grading. They should also include instructions for the construction of driveways, walks, retaining walls, and fencing.

5.1.5 Building Design.

5.1.5.1 The size of a building used to house microwave equipment depends upon the station function. In particular the following factors must be considered.

a. Size and quantity of required equipment and possible future equipment.

b. Necessary working space around equipment.

c. Required space for maintenance purposes.

d. Personnel requirements (desk space, sanitary facilities).

e. Housing of power equipment.

5.1.5.2 At some sites, contemplated use of existing buildings necessitates investigation of load bearing capabilities of the floor. The need for heavy antenna mounts on the building may require building reinforcement.

5.1.5.3 At remote sites new buildings may be erected. The type of construction depends upon physical conditions peculiar to the locality, and availability and relative cost of construction materials. Other considerations include the required strength and durability of the building, and necessary maintenance. Additional factors affecting the type and strength of a structure are: climatic conditions, temperature range, wind velocities, and amount of rainfall and/or snowfall. Transportation and handling costs and site accessibility affect the selection of construction materials. Local codes governing the use of certain materials and methods of construction must be investigated. The availability of skilled labor may be a deciding factor. In areas where a considerable amount of snow and high winds are to be expected, such as mountain top sites, enclosed walkways should be provided between buildings. Also suitable provisions should be made to ensure that the access road can be kept open.

5.1.5.4 For small stations the above requirements can be met by using either sheet metal or masonry construction. Sheet metal buildings can be prefabricated, easily erected, and readily enlarged or relocated if need be. Masonry buildings have greater durability.

5.1.5.5 For each building an Architectural and Engineering (A&E) drawing package that includes the following categories of plans should be prepared:

a. Civil Plans - site, grading and utility plan, sections, profiles, details, and boring logs.

b. Architectural Plans - floor plans, elevations, details, schedules etc.

c. Structural Plans - foundations, roof and wall sections, elevations construction details, etc.

d. Electrical Plans - electrical distribution, power distribution, control panels, lighting schematics, grounding plans and details.

e. Mechanical Plans - heating, ventilation, and air conditioning plans, diagrams and details.

f. Plumbing Plans - water supply and sanitation facilities plans, diagrams and details.

5.1.5.6 The equipment to satisfy the initial communications requirements determines the floor space requirements of the station. The kind and quantity of equipment as well as the type of operation dictates space to be provided for the electronics bays plus power and other corollary equipments and for personnel. If at all practical the equipment layout should be planned in such a manner as to afford sufficient space for the installation of equipment capable of handling the maximum projected traffic load. The initial equipment layout should be such that ultimate expansion of the station facility can be accomplished without extensively rearranging already installed equipment. Allowance of space for future equipment can be determined if specific equipments for future installation are known; otherwise, an estimate based upon the requirements of similar equipments should be made. When planning a new communications facility, the engineer should take into consideration the possibility of installing additional equipment in the floor space being provided. The expansion capability for future growth should be determined on a site-by-site basis, based on many factors, such as anticipated need, cost, etc. In addition, its design should include a capability to enlarge the station from at least one wall. Specific building design criteria associated with communications station requirements are discussed in the following paragraphs.

5.1.5.7 Building of single story, rectangular construction are most common for exclusive utilization by microwave radio communications installations. Equipment buildings may be physically separated from other site buildings such as power generator buildings and living quarters. When a single building is employed, one end would normally be used as the equipment room, the center of the building for maintenance and storage, and the opposite end for administrative functions at the station. A good way to segregate a single, all-purpose, microwave radio communications building is to have one wing for communications equipment, a second wing for power generators, and others for living quarters and offices. Storage and maintenance should be situated close to the communications equipment area. Buildings with multiple stories also afford easy segregation of functions.

5.1.5.8 To determine the space requirements and layout of the building, floor plans should be developed showing the location of all equipment in the operations and maintenance areas. Requirements for spare parts storage space are determined by the types of equipment, and level maintenance to be performed at the station. Consideration should be given to the reduction of spare parts storage requirements resulting from improved equipments, and streamlined maintenance and supply technique now being employed. Space requirements for administrative and sanitation facilities are determined from the number of personnel programmed for normal operation and maintenance duty at the station.

5.1.5.9 At least one outside door to the equipment room, capable of passing the largest single component that may be moved into the station is required. A loading ramp or dock must be provided immediately outside this door to facilitate loading and unloading heavy equipment from trucks. If the building floor is at ground level, hardstand should be provided from the drive to the equipment room freight door.

5.1.5.10 Ceilings in the equipment area should be at least 10 feet above the floor level for adequate ventilation of standard eight-foot equipment racks. This height also provides proper diffusion of light throughout the equipment area from ceiling luminaries. In the case of large installations a unistrut grid with 4 ft spacing is normally provided below the ceiling to provide support for the various cable racks or trays that may be required above the equipment bays for the equipment interconnecting cables and power distribution lines.

5.1.5.11 The building floor must be designed to support the heaviest item of equipment likely to be placed upon it as well as the total weight of all equipment on it. Overall, the floor should support the entire weight of all stationary and wheeled equipment, personnel, supplies, storage, and non-load bearing walls, and should provide sufficient overload factors to accommodate the installation of heavier or additional communications equipment for future expansion. To do this a minimum floor loading of 100 pounds per square foot is usually considered adequate.

5.1.5.12 Provisions must be made in the walls, ceiling and roof. of the equipment buildings for installation of transmission lines running to the outside of the building. These exit ports require "tailoring" to the installation at each station, and may include RF shielding.

5.1.5.13 Some microwave stations will require the installation of various types of hardware on the roof of the building such as roof ventilators (added by the building construction authority) and root mounted antennas (as required and specified by microwave LOS engineer) . A roof plan should be provided showing all pertinent details that will be required by the personnel responsible for the installation of the station. There are usually two major factors that will determine the specific location for the placement of antennas on top of a building. The first will be the location of the tower mounted reflector or the adjacent station to which the antenna will be directing a signal, and the second will be the relative location of the microwave equipment within the building. Having the antenna in proximity to the microwave equipment will avoid unnecessarily long waveguide runs. It should be recognized thought that the tower mounted antenna with transmission line is preferred over an antenna-to-tower mounted reflector (periscope) configuration.

5.1.5.14 For a station to be equipped with no break power, a room will have to be provided for a battery bank plus suitable space for a rectifier-charger unit.

5.1.5.15 The design of the interior lighting will be according to recommendations of the Illuminating Engineering Society (IES) Lighting Handbook. Specific location of the equipment cable racks, waveguide runs, unistrut grid, work benches, desks and consoles must all be considered in the design of the lighting system. Battery power emergency lighting is required throughout the building.

5.1.6 Station Ground.

5.1.6.1 The DCA Notice 310-70-1, entitled "DCS Interim Guidance on Grounding, Bonding, and Shielding", provides guidance for designing a good grounding system. The elements of a ground system for a communicantions standard are an earth electrode system, power grounding network, safety grounding network, lightning protection grounding network, a facility grounding network. and a Low frequency signal grounding network.

5.1.6.2 Earth Electrode System. The earth electrode system provides electrical contact with earth and is the common interconnection point for all the various grounding networks. The higher the soil resistivity, the more complex (and expensive) will be the electrode system necessary to achieve low resistance to earth. Two typical configurations of earth electrode systems are as follows:

a. Ten-foot ground rods installed at 20-foot intervals around the perimeter of the structure provide good utilization of the effective radius of the rod while providing several points of contact with the earth.

b. In regions of shallow bedrock, vertical ground rods may be ineffective and horizontal grids, wires, or plates must be used. A typical ground system of this type may consist of buried copper radials, extending in all directions from the building center, and a single ground point extended through the floor of the equipment room for connection of the electronic equipment.

5.1.6.3 Power Grounding and Safety Grounding Network. This is an integral part of the power system and should be done in accordance with the National Electrical Code.

5.1.6.4 Lightning Protection Grounding Network. This is an integral part of the construction of the building or antenna support structure. (See paragraph 5.4.2.3 on lightning protection.)

5.1.6.5 Facility Grounding Network. This network is a conductive grid providing multiple low resistance paths between any two points within the structure and between any point in the structure and the earth electrode system. The facility grounding system is to be separated from the low frequency signal grounding network, described in 5.1.6.6, except for the common interconnection made at the main ground plate of the earth electrode system.

5.1.6.6 Low Frequency Signal Grounding. The low frequency signal grounding network is used to furnish a single-point reference for low frequency signals, minimize power frequency noise levels in sensitive low frequency equipments and provide for fault protection and static discharge of otherwise isolated networks. Low frequency signals are defined as those with frequencies less than one megahertz.

5.1.6.7 Ordinarily, a microwave radio is interconnected with the facility grounding system. Frequency or time division multiplexing if included with the installation, should have its drop side grounded to the low frequency signal grounding network. The baseband cable between the radio and multiplexer or between radios at a repeater station should have its shield grounded to the low frequency signal grounding network if conducting signal currents with frequencies not exceeding one megahertz, or to the facility grounding system with frequencies over one megahertz. At small repeater stations, it may not be practical to have a separate low frequency signal grounding network; then the baseband cable shield would connect to the facility grounding network regardless of frequency. Whatever method employed, extreme care and sound judgement must be exercised because baseband cables are a critical means by which noise is introduced into radio systems. Grounding conductors will be stranded, insulated copper wire and adequately sized to conduct all currents likely to be imposed. Main grounding leads are usually run on the cable rack, tray or in trenches with signal cables.

Taps of smaller size wire are run from the main grounding lead to individual equipments. Connections to this main grounding lead are made with suitable lugs, pressure connectors or clamps.

SECTION 5.2 EQUIPMENT LAYOUT.

5.2.1 General.

5.2.1.1 Equipment layout should be standardized among the facilities comprising a communications system insofar as possible. In determining the layout, the necessary access for installation, maintenance and operation should be a major consideration. This would include such considerations as provision of adequate space between rows of equipment to allow for opening of cabinet doors or sliding out modules for maintenance. Another major but less important consideration is providing the shortest and most direct waveguide runs practicable.

5.2.1.2 Other equipment layout considerations include minimizing interbay cabling runs, provision for future expansion, and providing easy access for maintenance and operational convenience, etc. Sometimes the electromagnetic incompatibility of various types of equipment or inadequate ventilation for personnel and equipment can be problems. Equipment of the same type or with similar functions are usually grouped together except where impractical due to size and specific requirements of a station. In a typical situation radio/ multiplex equipment, crypto equipment, and technical control equipment are each grouped in separate rooms with other rooms being used for administration and maintenance.

5.2.1.3 Human engineering can be another factor of concern in laying out equipment. Equipments should be properly grouped according to their functions and interoperation. Care and thought should be given to the arrangement of meters, test equipment, jack fields, indicating lights, etc. to assure they are placed at the approximate eye level, thus allowing more rapid and convenient use. Equipment should not be mounted at the bottom of a bay, if it can be easily damaged or if its size and shape will interfere with power boxes or other hardware at the bottom of the cabinet or rack. Fortunately, most microwave radio equipment comes fully packaged with all components already mounted within the cabinet or rack.

5.2.1.4 It is advisable to arrange equipment within the equipment room in such a manner that expansion of the building will not necessitate rearrangement of existing installed equipment. A satisfactory arrangement is to align the equipment in rows on both sides of the building, with sufficient clearance between the rear of the equipment and the wall for use as an access/service area, and to provide an aisle between the front panels of facing equipment. The point of entry for antenna waveguide and possible transmission lines for this arrangement will generally be along the sides of the building. The end wall of the equipment room opposite the mechanical, generator, or toilet facilities should be considered as the direction for future building expansion. Therefore, installation of equipment at this room location should be avoided if possible. The end wall location may also be considered for use as an equipment ingress opening, by removal of wall panels, to permit installation or removal of equipment.

5.2.1.5 In determining floor area requirements for the communications equipment, a number of factors must be considered. The most important factor is that of providing sufficient space to suitably house all of the equipment and at the same time allow adequate clearance for ventilation and permit ready access for maintenance. When placing each piece of equipment, frequent reference should be made to the rack assembly and outline dimensional drawings with special regard to minimum wall clearance requirements, spacing between equipments, power and antenna connection points, and minimum radius requirements for the removal of protective housings and opening of maintenance access doors. Approximately three feet of clearance space, at a minimum, should be allowed in front of and to the rear of an equipment bay. If a bay does not permit rear access to equipment, the bay may be installed with no clearance on the back side, i.e., against a wall or back to back with other bays, ventilation requirements not withstanding.

5.2.1.6 The operational plan of the station must be studied to determine the communication circuit requirements when placing each component or rack assembly. In small stations it is recommended that the equipment be aligned in a row along one or, if need be, both sides of the building with sufficient space between to accommodate a normal floor traffic pattern. However, this type of layout will generally not be suitable in stations where large quantities of equipment are involved. In the larger station the most practical layout is usually one in which the equipment is aligned in bays across the width of the room, with sufficient space between bays to permit free access to each rack assembly.

5.2.2 Installation Plans.

5.2.2.1 After the equipment layout has been determined, installation plans can be developed. Installation plans contain all the information and instructions required to accomplish all aspects of the installation under the cognizance of the microwave communications system engineering activity. Some typical plans for specifying installations are explained in this section. The format of these engineering plans may vary from agency to agency.

5.2.2.2 Floor Plans. Floor plans provide a pictorial representation of equipment placement as well as administrative, maintenance and storage areas. All required dimensions must be specified on the floor plan with sufficient detail included relative to obstructions, to preclude interference with equipment placement.

5.2.2.3 Cable Rack Layout. Cables for interconnecting and terminating equipments are distributed by one or a combination of three methods: overhead open rack, overhead enclosed tray, or raised floor/floor trenches. Selection of one or a combination of these methods is dictated by the individual station equipment. Layout drawings should be prepared which depict:

a. Overhead view of cable layout superimposed on floor plan.

b. Detailed two-dimensional and perspective three-dimensional views of cable arrangements such as elbows, splits, tee sections, reducing sections and dropouts.

c. Equipment distribution frames and AC branching panel access details.

d. Rack/Cable support and hardware list of materials keyed to layout and details.

5.2.2.4 Cable Termination Lists. All VF and slow speed data signal equipment in a communications station is wired to a distribution frame (DF) as a common terminus for interconnection of circuits ingressing/ egressing all communications equipment. Information for terminating cables on a distribution frame is provided by cable termination lists. Each wire is given a specific punching assignment on a specific distribution frame termination block. A simple radio repeater station likely would not utilize a distribution frame, and the cable list would reflect runs directly from equipment to equipment. The microwave engineer would be concerned with wiring to the DF only to terminate the drop circuits on multiplexing equipment or to cable order wire and control and fault alarm circuits. See MIL-STD-188-310, "Subsystem Design and Engineering Standards for Technical Control Facilities", for a description of the breakout of individual circuits and their flow through a communications station.

5.2.2.5 Cross-Connect Lists. Assuming the station is large enough to have a distribution frame, cross-connect lists are used to identify or explain the connection of jumper wires on a distribution frame. This cross-connect list is required to interconnect a particular equipment group in a prescribed manner. Cross-connections could be the responsibility of the operating agency for expansion or replacement of equipment in an existing facility. For a turn-key project the cross-connections are part of a complete installation.

5.2.2.6 Power Distribution Drawings. Power wiring from the power distribution panel to each equipment is completely described by the power distribution drawings, including the method to be used by the installer in wiring individual electronic equipments to the power source. They specify such features as:

a. Type and size of wire to be used.

b. Routing of wires.

c. Specific circuit breakers (or fuses) associated with each equipment.

d. Diagrams of each panel board, indicating equipment connected to each circuit breaker, rating of the breaker and the load connected to each breaker.

e. For AC, tabulation of total loads on each phase of the panel feeder and the total load on all phases (of more concern to the power engineer than the communications engineer).

f. Materials required to accomplish installation of the power wiring.

g. Required power for each equipment.

5.2.2.7 Grounding Drawings. The station grounding system is shown by a grounding diagram that specifies ground system routing, cable size, type and position of all ground connectors and materials required to install the grounding system. Design of the station ground is outlined in paragraph 5.1.6.

5.2.2.8 Equipment Installation Drawings. All necessary information to accomplish installation of an equipment is provided by these drawings. They contain installation details peculiar to a specific equipment and illustrate the planned procedures for accomplishing each portion of the installation effort. When different equipments require the same basic installation information, a common installation drawing may be used. In either case materials required to install the equipment should appear.

5.2.2.9 Transmission Line Layout Drawing. This drawing shows the details of the RF transmission line and its routing. It specifies the size components to be used at each point along the route and where bends and flexible sections are to be located. The location of gas barriers and the arrangement of the pressurizing system should be shown.

5.2.2.10 List of Materials. A composite listing of materials required to install the facility should be included in the installation plan.

5.3 PRIME AND AUXILLARY POWER.

5.3.1 General.

5.3.1.1 Power systems shall be engineered to provide continuity of vital communications. The availability/reliability of the power system shall be based upon the operational requirements of the communication systems. The minimum electrical performance parameters shall be in accordance with MIL-HDBK-411.

5.3.2 Description of electrical power systems: The power systems for a LOS site shall consist of the following:

a. Primary Source: Commercial or "Class A".

b. Emergency: "Class C".

c. Floating Battery Plant: "Class D".

5.3.2.1 Primary Source: When available, commercial power will be utilized as the primary source. At isolated locations where the cost of providing commercial power is not justifiable, a "Class An plant shall be provided.

5.3.2.2 Emergency Source: A "Class C" engine driven generator with automatic start and control unit is required to provide power upon failure of the commercial source. The unit shall be sized to provide power for the total site load. NOTE : "Class C" power is not required where “Class A“ on site power plants are provided.

5.3.2.3 Floating Battery Plant "Class D”: A floating battery plant is required to provide continuous power to the critical technical loads. The system consists of batteres, rectifiers inverters, control panels, and distribution equipment. A minimum of two rectifiers shall be provided with each system. Each rectifier shall be sized for the full electronic tech load and for charging the batteries. This system is normally provided with the electronic equipment and is installed within the communication facility.

5.3.3 Power control and fault alarm panel: A power control and fault alarm panel for remote control and monitoring of the power system (AC and DC) with appropriate meters, relays, and switches shall be provided in the control area of the communication building. This control and alarm system shall have the capability of being remoted into the order wire system.

5.3.4 Fuel Storage Facility: The size of the fuel storage facility shall be specified in MIL-HDBK-411.

5.4 TOWER REQUIREMNETS.

5.4.1 General.

5.4.1.1 This section is for providing the communications engineer a description of the information required for a structural engineer to design or specify a tower and foundation adequate for its intended use. The information presented includes structural design considerations, design safety requirements, grounding for lightning protection and painting and lighting requirements.

5.4.2 Structural Design.

5.4.2.1 Microwave towers may be either self supporting towers or guyed towers. For permanent installations and main route high density applications, self supporting towers are preferred. They require less real estate than the same height guyed tower and offer more flexibility in the location of the antennas providing for possible future antenna relocation. For temporary or tactical applications, guyed towers may be more practical. The real estate required for tower guys is somewhat variable but does not usually exceed a circle with radius equal to tower height. Towers can be designed for almost any height; however, economic and practical considerate ions limit the maximum height to approximately 300 ft. or 100 meters for wideband communication use. This is not an absolute maximum but other alternatives should be carefully considered if higher towers seem to be required.

5.4.2.2 Tower and foundation design are dependent upon four main factors: (1) soil bearing capability at the specific location; (2) the size and number of the parabolic antennas and their location on the tower; (3) the meteorological conditions to be expected; and (4) the maximum tower twist and deflection (see section 4.4.30) that can be tolerated under worst conditions of Wind loading (and ice loading it applicable). Design of the required tower foundation is directly related to the tower design and the specific soil conditions involved.

5.4.2.3 Tower loading is the resultant of all forceS acting on the tower. Design of the tower must be such that with all antennas and other required items mounted on the tower, it will when subjected to maximum specified wind and ice conditions, resist any deflection or twisting beyond a specified amount.

5.4.2.4 Since the net result of all the tortes on the tower are also in effect transmitted to the foundation, it in turn must be capable of distributing the force over a large enough area and depth so as not to exceed the soil bearing pressure at any Point and also to resist movement in any direction. The depth of the foundation will be governed by the tower load and soil bearing characteristics, but in colder climates, it is necessary to extend the depth of the foundation below the frost line or to firm ground.

5.4.2.5 The soil bearing capability, usually designated as a pressure in pounds per square foot, is a determining factor in the design of a tower foundation. Table 5.4-1 illustrates the maximum soil bearing value for various types of soil conditions. Unfortunately, the designation of the various soil conditions are arbitrary in nature so the table should only be used as a rough guide for preliminary estimates. Soil borings taken at the area in question are normally required for a final design.

5.4.2.6 The following type of information must be provided by the communications engineer in order for the tower designer to adequately design a suitable tower and foundation combination.

a. Size and type of antennas required and type of radomes.

b. Azimuth and elevation angles for each antenna.

c. Amount of adjustment required for alignment after installation. (Normally, plus or minus 5 degrees in both azimuth and elevation.)

d. Height above ground for each antenna.

Table 5 .4-l Maximum Soil Bearing Capabilit y

MATERIAL	MAXIMUM ALLOWABLE BEARING VALUE (LB PER SQ FT)
BedrOCk (sound) without laminations	200,000
Slate (sound)	70,000
Shale (sound)	20,000
Residual deposits of broken bedrock	20,000
Hardpen	20*000
Gravel (Compact)	10,000
Gravel (loose)	8,000
Sand, coarse (canpact)	8,000
Sand, coarse (loose)	6,000
sand, fine (compact)	6,000
sand, fine (loose)	2,000
Hard clay	12,000
Medium clay	8,000
Soft clay	2,000

e. Location of tower with respect to the building and their corresponding orientations.

f. Beam widths of the antennas and permissible twist and deflection of the tower that can be tolerated under maximum expected wind and ice loading.

g. Type and number of waveguide runs required and power cabling for feedhorm or radome heaters.

h. Requirements for tower lighting, obstruction lights, lightning protection grounding systems, and painting.

i. Requirements for platforms to allow access to the antennas for maintenance and/or alignment.

j. Required means of access up the tower including required personnel safety features.

k. Provisions for future antenna requirements.

l. Climatic details of the area involved.

m. Local restrictions and/or other constraints that may be involved.

n. Soil conditions.

5.4.3 Tower Safety.

5.4.3.1 Tower safety is concerned in two areas: (1) the safety of personnel using the structure, and (2) the hazard imposed by the tower to aircraft.

5.4.3.1.1 The hazard imposed to aircraft by the tower is minimized in two ways: (1) painting and lighting, and (2) restriction against tower installation. Painting and lighting is covered by para 5.4.50 Restriction against installation is covered by A FM 86-8, Airfield Clearance Criteria. For installation in a foreign country, the siting engineer must check for clear zone or height restrictions that may exceed those in AFM 86-8.

5.4.3.1.2 The safety features required to protect personnel when working on the tower must be included in the tower design. Design requirements for ladders, stairs and elevated work platforms are specified in OSHA, Volume I, General Industry Standards. Requirements for ladder climbing safety devices are stated in AFM 127-101 and OSHA, Volume I, General Industry Standards.

5.4.4 Lightning Protection for Towers.

5.4.4.1 Lightning protection must be considered as part of each tower installation. Lightning protection for towers shall be in accordance with the latest edition of Underwriters Lab (UL), Pamphlet 96A, Lightning Protection Systems. Common grounding of lightning protection ground with existing facility grounding systems shall be provided. Air terminals, down leads, and a low resistance ground are basic requirements for adequate protection of towers. Materials for this system will meet requirements of UL 96. Waveguide on tower will be grounded before it enters building.

5.4.4.2 Any and all equipment mounted on a tower shall be fastened so that it is effectively grounded through the tower. On structures provided with obstruction lights, it may be desirable to place suitable lightning surge arrestors on wires supplying these lights.

5.4.4.3 The maximum permissible ground resistance to true earth of earth electrode system for tower prior to connection to down leads is 10 ohms. However, if 10 ohms is impossible due to tower sitting on a solid rock location, an extensive wire counterpoise system with radials (copper cables) extending from corners of counterpoise may be substituted versus an earth electrode system. Minimum Number 2 AWG bare copper wire should be used for counterpoise and radial ground system.

5.4.5 Painting and Lighting Requirements,

5.4.5.1 The guidelines and requirements contained in this section apply primarily to installations within the United States. In overseas installations regulations imposed by cognizant military and/or government agencies must be studied. To prevent excessive hazards to air commerce, antenna towers and similar structures must be marked in such a way as to make them conspicuous when viewed from aircraft. The type of marking to be used depends in part on the height of the structure, its location with respect to other nearby objects, and its proximity to aircraft traffic routes near landing areas. Requirements and specifications for marking and lighting potential hazards to air navigation have been established through joint cooperation of the Federal Aviation Agency, Federal Communications Commission, Department of Defense and appropriate branches of the broadcasting and aviation industries. The specifications determined by these groups aid in the final decision as to whether a structure constitutes an obstruction to air navigation. When conducting the preliminary site survey, it is advisable to determine the prevailing ordinances concerning such structures, and perhaps to discuss them with local government and building authorities. When dealing with locations within the continental limits of the United States, the latest copies of Government

Rules and Regulations, FCC Form 715, FCC Rule, Part 17, and FAA Standards for Marking and Lighting Obstructions to Air Navigation, with all revisions should be consulted. These rules not only apply to specifications for antenna structures, but also set forth the forms which must be submitted to the FCC, FAA, and Us. cost and Geodetic Survey (FCC Form 401A Revised, FAA Form 117, FAA Form ACA-114, and G&GS Form 844).

5.4.5.2 In order to warn airmen of the presence of obstructions during daylight hours in good weather conditions, all structures that may present a hazard to air commerce will be painted from top to bottom in accordance with requirements of the latest edition of FAA-AC 70/7460-1( ).

5.4.5.3 Both the FCC and FAA lighting specifications are set forth in terms of the heights of the antenna structures. The requirements for towers and obstructions will be determined from FAA Specifications specified in the latest edition of AC 70/7460-1( ). The specifications further stipulate that placement of the lights on either square or rectangular towers shall be such that at least one top or side light be visable from any angle of approach. When a flashing beam is required, it shall be equipped with a flashing mechanism capable of producing not more than 40 nor less than 12 flashes per minute with a period of darkness equal to one-half the luminous period.

5 .4.5.4 When the tower structure is in the process of construction, the FCC and FAA require that temporary lights, consisting of at least two 100-watt lamps enclosed in aviation red globes be displayed at the top of the structure from sunset to sunrise. Lights must also be installed at intermediate heights, if necessary IAW FAA requirements.

5.4.5.5 The FCC requires that tower lighting be exhibited during the period from sunset to sunrise unless otherwise specified. At unattended microwave installations, a dependable automatic obstruction-lighting control device must be provided. A light-sensitive control device will be used to control the obstruction lighting in lieu of manual control. This requirement will be met in microwave installations by employing a tower lighting kit. These kits apply power to the lights when the north skylight intensity is less than approximately 35 foot candles and disconnect the power when the north skylight intensity is greater than approximately 58 foot candles.

5.4.5.6 To insure the proper operation of tower lights, the FCC specifies that the lights be inspected at least once every 24 hours; the inspection can be performed either by direct observation or by observation of an automatic and properly maintained indicator designed to register failure of such lights. Where obstruction lighting is not readily accessible for periodic inspection, the rules permit use of electric signaling devices to indicate lamp failure. Should the fault alarm system register a failure in obstruction or beacon lighting, the failure must be reported to the nearest Airways Communication Station of the Federal Aviation Agency. The FAA must be notified of any code beacon, rotating beacon, or top light failure if not corrected within 30 minutes after failure.

5.5 ENVIRONMENTAL CONTROL

5.5.1 General. This section provides as general guidance and assistance to the mechanical environmental design engineer to indicate the basis for design which will be supplemented by specific design criteria based on the technical characteristics of the equipment concerned. It is not the intent to dictate specific design approaches but to portray general guidelines to be considered. Each individual mission will require initiative, imagination? and sound engineering judgement to meet the circumstances involved. Radical departures from the standards and guidelines noted herein will require coordination of DCA and the appropriate Military Department Field Engineering Office.

5.5.2 Environmental Control Systems. Environmental control as used in this handbook includes all equipments used for cooling, heating, ventilation, humidification, dehumidification, filtration, pressurization, and distribution of air and the control thereof. Environmental control as defined here is for the communications equipment and all systems, personnel and facilities that directly support these items.

5.5.2.1 This section provides general guidance for the selection of desired environmental conditions. The information contained herein will have to be supplemented by more specific environmental design criteria based on the requirements of the communications equipment to be installed.

5.5.2.2 When installed equipments operating range requires environmental conditions that are different than those outlined in this document, those requirements shall be used as a basis for design; however, every effort should be made to minimize life cycle costs.

5.5.2.3 For further design guidance, refer to the design manuals of DOD design and user agencies and the Defense Communications Agency (DCA). The latest edition of the American Society of Heating, Refrigeration and Air Conditioning Engineers Guide and Data Books - fundamentals, applications, systems, and equipment volumes - should be followed as a basic reference for system design except where modified by more specific criteria including MIL-HDBK-411.

5.5.3 Design Conditions - Electronic Equipment Spaces.

5.5.3.1 Outside conditions to be used as a basis for design shall be taken from the Army, Navy, and Air Force Manual, Engineering Weather Data, TM 5-785/NAVFAC P-89/AFM 88-8. The 1 percent and 99 percent temperatures for cooling and heating respectively shall be used for those facilities classed as critical. Al 1 other facilities shall use the 2 1/2 percent and 97 1/2 percent temperatures for cooling and heating respectively.

If conditions are not available from one of these manuals for a particular site the United States Air Force Environmental Technical Applications Center, Scott AFB, IL 62225 should be contacted for the necessary data.

5.5.3.2 Inside Design Conditions:

a. Winter dry bulb temperature shall be 70 degrees F.

b. Summer dry bulb temperature shall be 78 degrees F.

co Relative humidity shall be maintained between 20 and 50 percent and shall utilize a minimum of humidification and dehumidification during the winter and summer respectively.

d. supply air shall be filtered by filters with a minimum efficiency of 10 percent when tested by the ASHRAE dust spot test method using atmospheric dust.

5*5*4 Design Conditions - Auxiliary Equipment Rooms.

5.5.4.1 Outside design conditions shall be as referenced in paragraph 5.5.2.1.

5.5.4.2 Inside Design Conditions:

a. Equipment rooms such as battery rooms, environmental control equipment rooms, and uninterruptible power system rooms may not require as close environmental control as does the electronic equipment spaces. If this is the case, dry bulb temperature limitations are 104 degrees F, dry bulb maximum, and 50 degrees F, dry bulb minimum, and forced air cooling shall be provided as necessary if environmental conditions can be maintained without the use of mechanical refrigeration.

SECTION 5.6 TRANSMISSION LINES.

5.6.1 General.

5.6.1.1 For the purpose of this handbook, discussion regarding radio frequency transmission lines will be restricted to the waveguide system which interfaces the antennas with their respective transmitters and receivers. While coaxial RF transmission lines may be used for some LOS applications, their use is generally limited to frequencies of two GHz and below and will not be considered here. A source of reference for additional information is MIL-HDBK-216, "RF Transmission Lines and Fittings".

5.6.2 Waveguide Types

5.6.2.1 The three types of waveguide commonly used for LOS applications are:

a. Rectangular

b. Circular

c. Elliptical

5.6.2.2 Each of the three types have certain advantages and certain disadvantages both from technical and economic aspects. The choice of a specific type will therefore be dependent upon the specific application and must be determined by the design engineer with due consideration of all the factors involved.

5.6.2.3 Various manufacturers offer rigid, rectangular waveguide in various standard lengths with a typical maximum of 10 feet. Lengths other than standard may be obtained on special order up to a maximum of 20 feet. In addition a wide variety of standard bends, twists, and flexible sections are available. One of the disadvantages of rectangular waveguide is the multiplicity of joints required in a complete run with each joint a potential trouble point. Another disadvantage is that it will only accommodate one polarization so in those cases where dual polarized antennas are to be used it will be necessary to have two complete waveguide runs to the antenna.

5.6.2.4 The two big advantages for circular waveguide are its low attenuation, approximately half that of rectangular or elliptical and its capability for supporting two polarizations on a single waveguide run. These two advantages can be of great benefit in high capacity systems utilizing dual polarization or where high towers are required with consequent long runs of waveguide. Another desirable characteristic is relatively low return loss. The disadvantages are that it is essentially only useful for straight runs and requires great care in handling and installation and considerably more expertise in adjustment for minimum loss and maximum polarization isolation. Signal distortion and noise can also be a problem because of the variety of transverse modes that can propagate in circular waveguide, and to alleviate the problem, the waveguide run must be terminated with some form of mode suppression. As a practical matter some systems utilize a hybrid arrangement with circular waveguide for the long straight run up the tower and either elliptical or rectangular runs from the equipment to the bottom of the tower and thence via a rectangular-to-circular transition to the circular waveguide.

5.6.2.5 Elliptical Waveguide. The advantages for elliptical waveguide are its availability in almost any continuous length required and its semiflexible characteristic. It thus offers the possibility for a long continuous run without joints except for the two ends. Its attenuation characteristic is approximately the same as equivalent rectangular waveguide. Its main disadvantages are the comparatively large bending radius required, the skill required to properly attach the elliptical-to-rectangular transitions which are normally required at each end, and the restriction of only one polarization. A continuous section of rigid, rectangular waveguide typically exhibits somewhat less return loss than a comparable elliptical section but this advantage with rectangular is offset if a long run and, consequently several junctions are required.

5.6.3 Wavegide Layout and Installation.

5.6.3.1 Waveguide runs should be kept as short and direct as practical to minimize line loss.

5.6.3.2 Where waveguide has to be run horizontally from a building out to a vertical run on a tower, a waveguide bridge should be used and arranged to be provided through civil engineering support action. The bridge should be designed for all planned and anticipated loads. provided with waveguide hanger mount and protected against hazards such as ice falling from the tower.

5.6.3.3 Waveguide clamps/hangers are made specifically for each type of waveguide. These clamps are used for securing the waveguide to towers, bridges and other supports. Standoffs may be necessary with the clamps, especially on towers. Clamps are commonly spaced at four to five foot intervals for rectangular and elliptical waveguide and eight to twelve feet for circular; however, the manufacturer's instructions for the waveguide being used should be observed.

5.6.3.4 Allowance should be made for expansion and contraction of waveguide. For example circular waveguide is firmly and rigidly secured to the midpoint - or alternately to the top - of a tower and sliding hangers attached above and below the midpoint to allow the waveguide to expand or contract.

5.6.3.5 Flexible, rectangular waveguide sections are intended for situations not tolerating rigidity nor conveniently permitting a precise fit. Providing for expansion and contraction of rigid waveguide on a tower is a good application. A flexible section at the antenna permits both the waveguide to change length and the antenna to be moved for alignment. At the base of the tower a flexible section allows both changes in waveguide length and motion of the tower with respect to the building. Proper layout not permitting at the microwave equipment a flexible section may be used to align the transmission waveguide with the radio port. In a mobile shelter flexible waveguide can relieve strain between microwave equipment and shelter while they are in motion. The particular waveguide manufacturer s data should be consulted for exact limits of flexibility since they vary widely with size, which in turn is a function of frequency. Elliptical waveguide runs eliminate the need for flexible, rectangular sections. Although flexible waveguide is an expedient when faced with difficult problems of physical installation, its use should be kept to a bare minimum or avoided if possible because of high attenuation and, more importantly, because of low return loss (high VSWR) contributing to echo distortion.

5.6.4 Waveguide Components,

5 .6.4.1 Other items such as circulators, isolators, filters, duplexers and diplexers may be required in various combinations and are essentially a part of the overall waveguide system; although, one or more may also be supplied as an integral part of the radio. If any of these items are required externally from the radio equipment, consideration must be given to their placement and mounting in order to keep the waveguide run as short and direct as possible and to minimize the need for a multitude of bends, twists, etc.

5.6.4.2 All external waveguide runs should be pressurized with dry air or an inert gas. while standard tanks of nitrogen may be used for this purpose, the use of automatic dehydrator-pressurization equipment is generally preferred. The pressure should not exceed the manufacturer-s recommendation for the particular waveguide involved. This is generally on the order of two to ten pounds per square inch gauge. Pressure windows are available to isolate pressurized from unpressurized portions of the waveguide.

SECTION 5.7 AUXILIARY EQUIPMENT FOR OPERATION/MAINTENANCE.

5.7.1 Fault Alarm System.

5.7.1.1 The fault alarm system should indicate problems that cause system degradation and failure. These indications are effected by monitoring equipment/environment parameters and " remotely controlling some radio operations for testing, etc. The design of these functions varies greatly depending upon system requirements, e.g., system maintenance philosophy, manning/non-manning of sites, location of maintenance centers, etc.

5.7.1.2 For the simplest case, the fault alarm system may monitor those functions normally monitored/displayed by equipment warning lights. On the other hand, an unattended site may require a very extensive reporting and control system to report items such as the following:

a. Site intrusion

b. Fire/high temperature

c. Tower lighting failure

d. Primary/standby power failure

e. Engine/generator

f. Waveguide pressure

g. Multiplex operation

h. Radio operation

(1) Primary transmitter fail/standby transmitter operating

(2) Continuity of pilot in all transmitters

(3) Excessive noise/loss of pilots by any receiver

(4) Low received signal level of any receiver

(5) IF resupply switch over operation.

i. Test of fault alarm system.

5.7.1.3 Remote controls are employed for testing and fault isolation e.g., switch to standby power, switch to standby transmitter, switch to standby receiver, and a return to normal operation.

5.7.1.4 Other parameters, which are useful in system operation, can be remoted to give a relative indication of system performance, as opposed to absolute indications like alarm points. Some parameters such as received signal level (RSL) and amount of distortion in the baseband signal or digital stream, provide a more accurate indication of the quality of communications. These parameters require an analog to digital (A/D) converter to encode the data such that it can be transmitted by the alarm data. Some of these parameters are useful directly and require no further conversion at the master fault alarm equipment at manned sites. However, other parameters, e.g., RSL, which uses an intermediate value (voltage measured at the IF), must be converted to the original desired value, in this case, power. For this reason, and to improve the display format for clarity, a programmable device should be incorporated.

5.7.2 Maintenance Communications and Orderwire,

5.7.2.1 Maintenance communications is by means of a service channel (also known as maintenance coordination circuit or maintenance orderwire) and is used solely by maintenance personnel for aligning, testing and repairing the microwave and associated wideband communicant ions equipment. The service channel is an integral part of the radio and has a separate signal input port or may be part of a combined input for supervisory voice and teletype communications and control and fault alarm signals. the service channel/supervisory port is independent of the mission communications traffic and is not jeopardized by a potential malfunction of the main multiplexing equipment while being more easily injected into or recovered from the RF modulation at an intermediate station. A service channel normally exists between each end of a single, point-to-point radio path.

5.7.2.2 Orderwires provide intersite coordination among operations personnel performing the job of technical controller. Orderwires are communication channels which, depending upon operational requirements, may or may not be funneled through the mission traffic multiplexing equipment. Usually, the microwave radio engineer would have very much involvement only if the orderwire circuit is to have direct entry into the radio; otherwise, the orderwire would be treated as any other customer circuit over the communications system. Orderwires are beneficial mainly with communications networks, either tactical or fixed, rather than single, isolated radio hops. The most sophisticated orderwire system within the DOD is being developed for the Defense Communications System. The DCS orderwires are explained in DCA Circular 310-50-6, "Defense Communication System Orderwire Concept".

5.7.2.3 System requirements may dictate the use of a hybrid maintenance and order wire circuit. Situations requiring this kind of orderwire might be where maintenance personnel perform the duties of a technical (or tech) controller or where Party line circuits are established to bridge the various repeater stations of a multihop system, and both a maintenance and tech control circuit are not required. This class of circuit is out of mission traffic and is commonly called "link” orderwire.

SECTION 5.8 ELECTROMAGNETIC COMPATIBILITY.

5.8.1 General.

5.8.1.1 The intent of this section is to acquaint the communications engineer with general guidelines concerning electromagnetic compatibility. (EMC) as it relates to his facility design.

5.8.1.2 The extent of involvement with EMC on the part of the communications project engineer will vary depending upon many factors. Generally the involvement will depend upon the degree of need for EMC control which is to ask the question, "how complex a project is it?" It will also depend upon how much EMC training the project engineer himself has had. Normally, the communications engineer will seek the advice and guidance of a specialist in EMC. There are certain aspects of EMC engineering which are mandatory and act to confine or restrict the facility design work of the project engineer. For this reason even if the project engineer feels comfortable in performing his own EMC engineering he is best advised to contact the specialist early in his project in an effort to ward off unseen difficulty.

5.8.1.3 There are two general reasons for applying EMC engineering to a project. First, of course, the project engineer needs assurance that his project can be installed without suffering degradation from other facilities that may be nearby to his proposed siting. Of equal importance is the need to assure that his proposed facility will not interfere with the existing facilities, and that even if interference to other facilities is not anticipated, that his facility will not unduly pollute the environment. The term "unduly pollute" refers here to the use of the electromagnetic spectrum. Be advised that National and DoD policy is aimed at restricting the radiation of unnecessary RF energy. Among the new regulations that the communications project engineer must contend' with are those in the environmental protection area. These regulations are designed to implement the DoD'S, responsibilities in the national campaign against pollution of all kinds, i.e., pollution of air, water and general living conditions. Even radiation hazards to personnel are covered. The military or government engineer will find that the problem is most acute when what he does has a potential impact upon the civilian sector. Other regulations focus upon the protection of the electromagnetic spectrum and, in particular, the protection of the Defense Communications System and other DoD systems. For further guidance, refer to OTP Manual of Regulations and Procedures for Radio Frequency Management and DoD Directives 3.222.3, 4650.1, 5160.57, 5100.5, 5030.41, 6050.1, and DoD Instructions 5030.52, 4120.14, and 4170.6.

5.8.1.4 Interference Sources.

5.8.1.4.1 In Chapter 4 (link design) many noise sources and other interference sources were listed. Listed below are the main interference mechanisms which are usually involved in one kind of facility or another:

a. Direct co-channel interference.

b. Adjacent channel interference.

c. Spurious receiver responses.

d. Transmitter spurious output.

e. Case susceptibility.

f. Case radiation.

g. Conducted interference.

5.8.1.4.2 Fortunately, only a few of the above listed interference mechanisms are normally encountered in microwave point-to-point systems. All such mechanisms need to be considered but most can usually be rejected as problems early in the analysis. Obviously, if all of the above listed mechanisms are to be effectively considered, good technical data on all of the involved equipment is necessarily required. In the absence of good technical data, the facility or EMC engineer will have to guess at probable parameters. Fortunately, most all communications equipment (except that designed for the civilian sector) is manufactured uncle r military specifications which require EMC testing and data development.

5.8.1.5 Military specifications on EMC, such as MIL-STD-461, 462 and 463, are excellent for the intened purpose. Such specifications are intended to control and achieve an acceptable figure of merit or quality in the development of new communications equipment. They do not eliminate the need for EMC engineering in facility design. Frequency selection, nearness to other facilities and, to some extent, the facility design itself are (in addition to equipment quality) variables in the interference generation problem.

5.8.2 EMC problems to be expected in microwave systems.

5.8.2.1 There are two general areas to consider during EMC analyses.

a. Self induced interference.

b. Interference involving other systems.

5.8.2.2 Self induced interference may result, if care is not exercised, in the selection of equipment that will form a system. Virtually all electronic equipment will exhibit some EMC parameter weakness. If the system engineer plans to employ prototype testing, the effect (if any) of these weaknesses will become known before a final commitment is made. The spurious signal output (radiated or conducted) of one equipment (a MUX, for instance) affecting some other part of the system is a mechanism which should be checked during such testing. If prototyping is not employed, then a desk study of the known equipment weaknesses (MIL-STDS-461 or 449 data) should be performed. Another form of self induced interference may result from improper frequency assignment where repeater stations are involved in the system. For example, the signal from one station may overshoot its intended receive station and interfere with a third station in the system. Careful frequency selection will usually solve this problem, although other solutions are possible.

5.8.2.3 Microwave point-to-point facilities, which are usually of very low operating power and use directional antennas, do not offer much of an interference threat to other systems even when collocated with them. Due mainly to the directional characteristics of the microwave antennas, the potential for interference to microwave systems are diminished over that of some other systems. However, those mechanisms of interference which do not involve coupling via the antenna are very much of a problem if the equipment is sited in proximity to high power radiators or if power lines and control lines are noisy. Experience has shown that much of the signal processing equipment in particular, exhibit case penetration problems. But, again, this only poses a problem when such equipments are collocated or in proximity to other equipment. When microwave equipment is to be located in such proximity, an on-site survey with actual measurement of field intensities involved is often required and prudent. In other cases, a desk top study may suffice to clarify the situation.

5.8.3 Engineering Team approach to Design.

5.8.3.1 The usual approach taken by communications engineers is to make the EMC engineer a part of his team and to request that he provide all guidance in the EMC area He may, depending upon the nature and complexity of the project, request the assistance of the Electromagnetic Compatibility Analysis Center (ECAC). In most cases, the EMC engineer will only request data base output from ECAC and perform his own analysis. If he feels the analysis task is beyond his in-house capability, he may request a complete ECAC study of the problem. (See para 4.2.33.4.) In any case, the project engineer is advised to become familiar with his Service-s engineering guidance documents on electromagnetic compatibility. Such documents will greatly augment the guidance given herein, especially in the areas of power density or field intensity calculation and antenna near field correction methods. At the time of this writing, there are no known tri-service EMC engineering guidance documents. There are some possible candidates for such standardization belonging to each military service and the standardization groups are working toward greater standardization.

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CHAPTER 6

ADDITIONAL ENGINEERING PROCEDURES

Section 6.0 INTRODUCTION.

6.0.1 This chapter contains details of engineering procedures applicable to LOS facilities.

Section 6.1 DETERMINATION OF AZIMUTH FROM OBSERVATIONS OF POLARIS.

6.1.1 Introduction.

6.1.1.1 Polaris is a fairly bright (second magnitude) star located about one degree from the north celestial pole. It rotates about the pole in a counterclockwise direction (as viewed from the earth) approximately once in 24 hours, and the elevation angle of the star is always within one degree of the observer's latitude. The star is easily located by reference to the Big Dipper (Ursa Major); it is on the extension of a line through the two stars on the side of the "bowl" most remote from the handle, and there are no other stars of similar magnitude in the vicinity of Polaris. This relationships shown approximately in the figure below:

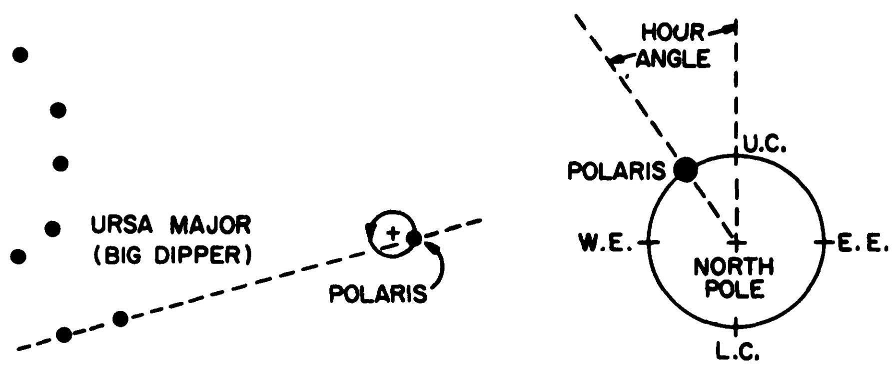


Figure 6.1-1 Polaris Location and Movement

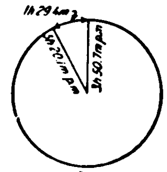
6.1.1.2 Polaris crosses the (observer's meridian twice in its daily circuit of the NorthPole; once at upper culmination (U.C.) and once at lower culmination (L.C.). The points of maximum easterly and westerly movement are called eastern elongation (E.E.) and western elongation (W.E.). At the instant of elongation, the relative horizontal movement is zero.

6. 1.1.3 The interval between the time of passage of Polaris over the observer's meridian and any other position in its diurnal circle is called the hour angle; usually the point of reference is upper culmination, and the interval may be measured either in units of time or in angular degrees, minutes, and seconds. The mean time hour angle of Polaris west of the observer's meridian is the mean time interval from the local mean time (LMT) of the last preceding U. C. to the local mean time of the observation of Polaris (see preceding figure). An hour angle east of the meridian is the mean time interval from the LMT of the next succeeding U. C. of Polaris. These relationships are illustrated in the examples of hour angle calculations shown in figure 6.1-2.

6. 1.1.4 The declination is the angular distance to the s tar as measured north from the equator; at present it is more than 89°. The term polar distance is sometimes used to denote the angular distance from Polaris to the pole.

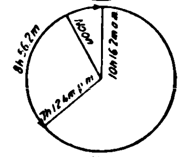
6. 1.1.5 Azimuth determinations generally require accurate time observations, since the azimuth of Polaris varies with the local mean time; however, azimuths can be determined by observation of Polaris at elongation even if only the approximate time is available. This technique frequently requires observations at an inconvenient time of day, and if clouds or fog happen to obscure the star at the time of elongation it becomes necessary to delay subsequent observations until the following night. Considering the present availability of highly accurate watches and the worldwide availability of standard time broadcasts (e.g., WWV (U.S.), JJY (Japan), MSF (England)), it should seldom be necessary to resort to the elongation method. The "hour-angle" method [95, 91] permits azimuth determination at any time during the night, and even when the sun is 20 or 30 minutes above the horizon. Sunrise and sunset periods are, in fact, preferred times

Examples of computing hour angles of Polaris; all taken out for longitude 117°15′ W.:



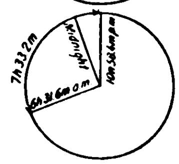
West of the meridian, p. m. obsn., U. C. in p. m.

Feb. 18, 1945, l. m. t. of obsn.		$=5^h20.1^m$ p. m.
Gr. U. C., same date	$=3^h\ 52.0^m$ p. m.	
Red. for long.	$=-1.3$	$=3\ 50.7$ p. m.
Hour angle, west		$=1^h29.4^m$......



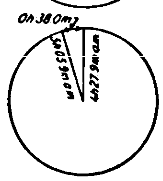
West of the meridian, p. m. obsn., U. C. in a. m.

May 14, 1945, l. m. t. of obsn.		$=\{+12$ $7^h12.4^m$ p. m.
Gr. U. C., same date	$=10^h17.5^m$ a. m.	
Red. for long.	$=-1.3$	$=10\ 16.2$ a. m.
Hour angle, west		$=8^h56.2^m$



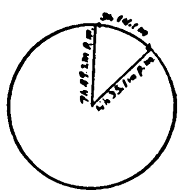
West of the meridian, a. m. obsn., U. C. in p. m.

Nov. 3, 1945, l. m. t. of obsn.		$=\{+12$ $6^h31.6^m$ a. m.
Gr. U. C., Nov. 2	$=10^h59.7^m$ p. m.	
Red. for long.	-1.3	$=10\ 58.4$ p. m
Hour angle, west		$=7^h33.2^m$



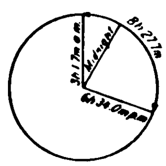
West of the meridian, a. m. obsn., U. C. in a. m.

Aug. 11, 1945, l. m. t. of obsn.		$=5^h05.9^m$ a. m
Gr. U. C., same date	$=4^h29.2^m$ a. m.	
Red. for long.	-1.3	$=4\ 27.9$ a. m.
Hour angle, west		$=0^h38.0^m$



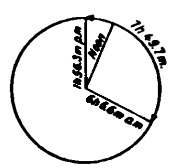
East of the meridian, p. m. obsn., U. C. in p. m.

Gr. U. C., Dec. 20, 1945	$=7^h\ 50.5^m$ p. m.
Red. for long.	$=-1.3$
L. M. T. of U. C., Dec. 20	$=7\ 49.2$ p. m.
L. M. T. of obsn., same date	$=4\ 35.1$ p. m.
Hour angle, east	$=3^h\ 14.1^m$



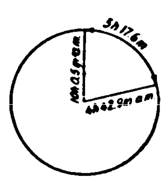
East of the meridian, p. m. obsn., U. C. in a. m.

Gr. U. C., Sept. 2, 1945	$=3^h\ 3.0^m$ a. m.
Red. for long.	$=-1.3$
L. M. T. of U. C., Sept. 2	$=\{3\ 1.7$ a. m. $+12$
L. M. T. of obsn., Sept. 1	$=6\ 34.0$ p. m.
Hour angle, east	$=8^h27.7^m$



East of the meridian, a. m. obsn., U. C. in p. m.

Gr. U. C., Mar. 19, 1945	$=1^h57.6^m$ p. m.
Red. for long.	$=-1.3$
L. M. T. of U. C., Mar. 19	$\{=1\ 56.3$ p. m. $+12$
L. M. T. of obsn., same date	$=6\ 6.6$ a. m.
Hour angle, east	$=7^h49.7^m$



East of the meridian, a. m. obsn., U. C. in a. m.

Gr. U. C., May 18, 1945	$=10^h\ 1.8^m$ a. m.
Red. for long.	-1.3
L. M. T. of U. C., May 18	$=10\ 0.5$ a. m.
L. M. T. of obsn.	$=4\ 42.9$ a. m.
Hour angle, east	$=5^h17.6^m$

Figure 6. 1.2 Examples of Computing Hour Angles of Polaris, both West and East of Meridian, with Diagrams

for these observations, since no artificial lighting is required for illumination of the theodolite cross hairs, and marks at the site can be easily seen. Very precise azimuth determinations are possible by this method; even at the most unfavorable time, when Polaris is near culmination, an error of as much as 1 minute in timing causes a bearing angle error of only O. 3 minute of arc at latitude 40° [96].

6. 1.1.6 Azimuths can be determined by observation of Polaris from about latitude 10° N to 65° N; for other northern latitudes, and for locations in the Southern Hemisphere, azimuths may be determined by reference to other stars or the sun. Star charts and tables for the reduction of observational data are contained in most ephemerides [90, 91] and the techniques are discussed in surveying manuals, such as those referenced in the preceding paragraph.

6. 1.2 Observational procedure

a. Set watch to exact standard time by monitoring a time broadcast station.

b. Set up the theodolite or transit, and carefully level the instrument.

c. Set up a mark at a distance of 100 to 200 meters from the observation station. If observations are planned for hours of total darkness, provision must be made for lighting the mark. Center the instrument on the mark (0° azimuth).

d. Focus telescope on a distant light or star.

e. Locate Polaris (see figure 6. l-l). Bisect the star, and note the exact time (if working alone, a s top watch may be useful). Record the horizontal angle from the mark to Polaris.

f. Reverse the telescope, bisect the star, and record time and horizontal angle.

g. With the telescope in the reversed position, again bisect the star and record time and angle.

h. Return the telescope to the direct position and make. a fourth observation.

i. Use the average watch time of the four observations to determine the correct local time of the Polaris observation.

j. Determine the mean horizontal angle from the mark to Polaris, and to this apply the azimuth of Polaris at the mean time of observation to obtain the true bearing of the reference mark.

k. Lay off a reference baseline on the site.

6.1.3 Determination of local mean time

6.1.3.1 The distinctions between the various time designations are important. Apparent time is based upon the real sun, with a day counted from the sun's meridian passage on one day to the meridian passage on the next. This rate is irregular. Mean solar time is based upon an imaginary sun whose day is uniform. This is the time generally used for civil purposes, while sidereal time is used by astronomers. A sidereal day is equivalent to 23 hours 56 minutes 4.091 seconds in mean solar time.

6.1.3.2 Local mean time is identical with mean solar time on the meridian where that time is employed, and standard time is the same as mean solar time on the central meridians of each time zone in the U.S. (e. g. , Eastern 'Standard Time is based on the 75th meridian time). Standard time is reckoned from the meridian passing through the observatory at Greenwich, England (longitude 0°); in this time zone standard time is called Greenwich Civil Time (G CT), Greenwich Mean Time (GMT), or Universal Time (U. T.). If we consider the apparent movement of the sun from east to west in the celestial sphere (the dome of the sky as viewed from a point on earth) we find that when the sun crosses the meridian at Greenwich it is noon or 1200 hours G CT, but it is not yet noon on meridians west of Greenwich, and noon has already passed at meridians east of Greenwich. Standard or mean solar time varies by one hour for each 15° of longitude, thus there is a difference of 5 hours between Greenwich and the 75th meridian in the U.S. Time zone boundaries are arbitrarily set, frequently to conform to political or geographical boundaries, and in some parts of the world the "official" time does not conform to a standard number of hours from Greenwich. For example, many countries in Europe which are in the Greenwich time zone have chosen to use Central European Time (based on the 15° E meridian) as their official time. Great caution must therefore be used in converting from the local official time to local mean time or Greenwich Civil Time.

6. 1.3.3 Tabular data in the ephemeris are listed for mean time at Greenwich, and calculations related to Polaris observations require the local mean time at the point of observation. It is usually convenient to use a watch set to standard time and correct the mean time of observation for the distance east or west of the standard meridian. Corrections are based upon the following relationships:

Longitude (arc)	Time
360°	24 hrs
15°	1 hr
1°	4 minutes
15′	1 minute
1′	4 seconds
15"	1 second
1"	0.067 second.

Note the distinction between minutes and seconds of arc (longitude) and minutes and seconds of time. A station east of a standard meridian will have a later LMT than a station on that meridian, and a station west of the meridian will have an earlier LMT.

6. 1.3.4 To illustrate the method of converting from standard time to LMT, consider the following example:

Latitude 40° 30′ 00″ N, Longitude 92° 30′ 10″ W.

Date: April 20, 1972

Mean watch time of observation: 18 hrs 27 min 55 sec CST.

Since the observation point is 2° 30' 10" west of the time zone meridian (90° W), the “sun” time or local mean time is somewhat earlier than it would be if the site were exactly on the 90th meridian. The correction is as follows:

2° = 8 minutes
30' = 2 minutes
10" = .67 seconds (or .01 min.)

Total correction = 10 min 0.67 see, or 10.01 min.

Applying this correction, we obtain

18 hr 27 min 55 sec
-10 min 0.67 sec

18 hr 17 min 54 see, or 18 hr 17.91 min Local Mean Time

If our site had been east of the meridian by the same amount (longitude 87° 29′ 50″ W) the correction would have been the same, but it would have been added to the time of observation (CST) to obtain LMT. Also, if the watch used is known to be fast or slow at the time of observation this must be taken into account.

6. 1.4 Hour angle determination

6. 1.4.1 After obtaining the LMT of the observation, we can proceed to the calculation of the hour angle. For the example mentioned above, we would refer to the table on page 3 of the Bureau of Land Management ephemeris [90], and find that on April 20, 1972 the upper culmination (U.C.) occurs at 12:09.0 p.m. and the declination is 89°08' 20.48". This time for U. C. is the mean time on the Greenwich Meridian, and mean time of U.C. on other meridians will be slightly different because of the difference between solar and sidereal time. Referring to the table on page 27, for 90° 30′ W longitude the correction is -1 min 01 see; therefore the local mean time of culmination at our observation point is 12:09.0 - 1.0 = 12:08.0 LMT. Now we draw an hour-angle diagram:

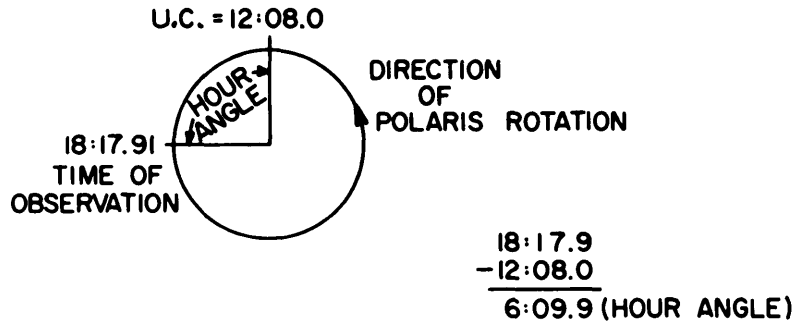


Figure 6.1-3 Example Hour-angle Diagram

A number of examples of hour-angle computations are given in figure 6.12.

6.1.5 Azimuth of polaris

6.1.5.1 Referring now to page 19 of the ephemeris, we enter the table with the hour angle and the station latitude, and find the azimuth by interpolation:

	Latitude		
Hour Angle	40°	40°30'	42°
6:09.0	67.1		69.2
6:09.9	67.082	67.6	69.182
6:19.0	66.9		69.0

To this value we make a correction for declination, obtained from the right-hand columns of page 19: +0. 2.

The corrected azimuth is 67.8', or 1°07.8'.

If we assume that the mean horizontal angle (mark to star) was 22° 30.1′,

$$\begin{array}{r} 22^\circ\ 30.1' \\ +1^\circ\ 07.8' \\ \hline 23^\circ\ 37.9' \end{array}$$

The true meridian is therefore 23° 37.9' to the east of the line connecting the mark and observation point. With this information available, we can lay off a true reference baseline at the site.

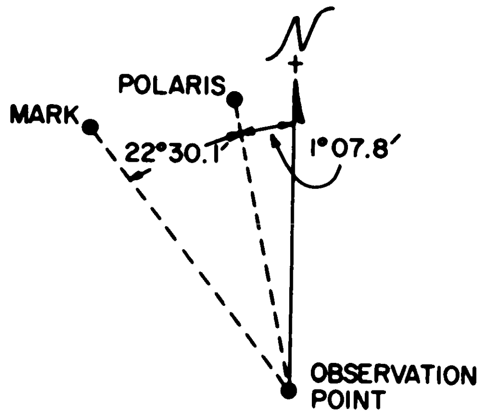


Figure 6.1-4 Example Baseline Diagram (diagram not drawn to scale).

6.1.5.2 The method outlined above for observing Polaris and calculating true azimuth is based upon material in the "Manual of Instructions for the Survey of the Public Lands of the United States" [95]. When using other ephemerides (for example, the Solar Ephemeris and Surveying Instrument Manual [91], slightly different procedures are followed. The various ephemerides are revised annually, with the issue for the coming year available in November or December.

6.1.6 Observation of Polaris by the elongation method

6.1.6.1 If, because of loss or damage to watches, accurate time is not available, azimuths may be determined accurately by the elongation method. The instrument is set up and leveled well in advance of the time of elongation indicated by the ephemeris (we assume that some crude timepiece is available). Check observations are made at intervals of a few minutes, and when the rate of change of azimuth begins to decrease, the observer is alerted that the time of elongation is approaching. When no change in azimuth is noted over 1 or 2 minutes (Polaris appears to move along the vertical cross hair) observations of the indicated azimuth should be started, and continued until horizontal movement of the star is again evident. observations should be alternated between direct and reversed position of the telescope; select a set of four readings that embrace the extreme position of the star and use the mean of these readings as the azimuth at elongation. Then enter the table on page 22 of the ephemeris [90] with the station latitude and determine the star to pole azimuth at the time of elongation. Then calculate the true bearing (mark to pole) as in the hour-angle method.

6.1.6.2 There is a period of about 15 minutes on either side of the point of elongation when the azimuthal change is only about 1' of arc, so nearly continuous observation during this period is recommended.

6.1.7 Checking of azimuth

6.1.7.1 It is recommended that the calculations for azimuth from the observational data be made independently by two members of the survey party.

Section 6.2 DETERMINATION OF ELEVATION BY ALTIMETER SURVEYS.

6.2.1 Altimeters are essentially aneroid barometers calibrated to indicate altitude instead of pressure. The pressure-height relationship is based upon an assumed "standard" atmosphere; these so-called standard conditions will seldom, if ever, be found in the real atmosphere, so that some error is nearly always present. A commonly used relationship for scale calibration of surveying altimeters is based upon the assumption of a completely dry, isothermal atmosphere with a uniform temperature of 10° C (50° F) and a sea-level pressure of 29.90 inches of mercury [92]. Since the sea-level pressure sometimes exceeds this value, an altimeter calibrated on this assumption will sometimes show negative values of altitude; this is avoided on other instruments by placing the scale zero at -1000 ft (pressure 31.026 inches) so that readings will always be positive. With the latter scale calibration, however, the indicated altitude is usually about 1000 ft higher than the true altitude.

6.2.2 Pressure always decreases with altitude, roughly at the rate of about one inch per 1000 ft; thus at 5000 ft above sea level the actual atmospheric pressure will be around 25 inches of mercury. Barometers (and altimeters) indicate the total weight of air above the point of observation; this varies with the temperature and humidity of the air masses and is greatly influenced by moving weather systems. Altimeter surveys should be conducted only during stable weather conditions, when winds are light and the pressure and temperature are reasonably steady over the survey area; operations should be suspended in stormy weather or when winds are high or gusty.

6.2.3 In spite of the limitations outlined above, the surveying altimeter is very useful for determining differences in elevation between two points, one of which is a benchmark or other location of known elevation. By making corrections for temperature and humidity differences (which affect the density of the air), horizontal and temporal changes in pressure, and scale calibration temperature, very rapid and accurate surveys can be obtained. It should be noted that the "scale calibration" correction is completely separate from the air temperature correction; the scale is engraved under laboratory conditions with a temperature of about 24° C (75° F), and when used in the field under different temperature conditions a slight scale change occurs.

6.2.4 The following general precautions are applicable to most surveying altimeters:

a. Handle the instrument as you would a good watch -- do not drop or jolt it, and pack in a padded case when shipping or moving in a vehicle.

b. Never expose the altimeter to the direct rays of the sun -- use in the shade, or shield with the body during observations. Avoid placing the instrument on hot pavement, rocks, metal roofs, etc.

c. Always read the instrument in the same position (normally horizontal) and be careful to avoid parallax errors -- if the dial has a reflector ring, make the reading when the pointer and its image appear coincident.

d. If there is a large change in temperature between two observation points, allow a period of time before the second reading to permit the instrument to reach thermal equilibrium.

e. Tap the case of the altimeter lightly with a finger or pencil eraser before reading; this helps reduce errors caused by mechanical lag or friction in the mechanism.

f. When several altimeters are used by a field party, it is a good practice to make comparative readings at least once each day and record the values in the field notebook. Any large change in the differences between instruments is reason to suspect possible instrument damage.

g. Avoid frequent resetting of the dial pointers in the field. It is better to make corrections to field readings based upon the most recent benchmark-to-altimeter comparison.

h. After checking an altimeter at a benchmark, observations at the various points in the field should be made as quickly as possible. Even when the general pressure systems are static there are regular diurnal variations that must be allowed for -- a sort of atmospheric tide. These diurnal variations have a 12-hour period and cause maxima at 1000 and 2200 local time, and minima at 0400 and 1600 [94]. In the tropics these are the most important pressure fluctuations and are very regular from day to day; in temperate and higher latitudes the diurnal effect is frequent masked by the larger pressure changes caused by moving pressure systems, but the “tidal” effect is still present.

6.2.5 There are a number of ways in which altimeter surveys can be conducted; the choice depends largely upon the personnel and number of instruments available, as well as the accuracy required from the particular survey. Two procedures will be described, the <u>single-base</u> method and the <u>two-base</u> method [93, 96].

6.2.6 In the single-base survey, two altimeters are required. One remains at a benchmark or other point of known elevation, with readings of the altimeter made at regular intervals -- say every 5 or 10 minutes. The other instrument, referred to as the roving altimeter, is read at the various points along the path where elevations are desired. At both stations, temperature and humidity measurements are obtained with small battery-powered psychrometers, or with the sling-type psychrometers packed in the case of many surveying altimeters. The indicated differences in elevation are corrected by a factor determined by the mean temperature and humidity over the path from benchmark to field point at the time of the field observation; tables or nomograms for the corrections are included with the altimeters. The corrected difference in elevation is then combined with the known elevation of the base station or benchmark to obtain the desired elevation field point. (Corrections may also be required for the scale temperature).

6.2.7 The two-base method. eliminates the need for temperature and humidity corrections, although the temperature must still be checked to determine if scale temperature corrections are necessary. One station is established at a low point in the area, and a second station at a high point; the points of unknown elevation are between these two stations. The elevations of the base stations must be known; if possible they should be located at benchmarks. A third altimeter is carried to the field sites where elevations are desired. All three altimeters are read simultaneously, either by prearranged schedule or by radio coordination. It is assumed that the atmospheric properties change linearly between the base stations at a given time, and that the ratio between the known base-station elevation difference and the altimeter-indicated difference is equal to the ratio between the unknown elevation difference from base station to field point and the difference indicated by simultaneous altimeter readings. For example,

$$\frac{\text{Upper base - Lower base (Elevation)}}{\text{Upper base - Lower base (Altimeter)}} = \frac{\text{Field Pt. - Lower base (Elevation)}}{\text{Field Pt. - Lower base (Altimeter)}}$$

$$\frac{1000 \text{ ft} - 400 \text{ ft}}{1200 \text{ ft} - 500 \text{ ft}} = \frac{X - 400}{800 - 500}$$

$$\frac{600}{700} = \frac{X - 400}{300}$$

$X - 400 = 300 \times 6/7$; or $X = 257 + 400 = 657$ ft (Elevation of field pt.)

Use of a computation sheet, such as that shown in figure 6.2-1, is recommended. The average error of elevations obtained with the two-base method is said to be 3 ft with the two base stations separated by 10 miles horizontally and 1000 ft vertically.

6.2.8 There will be occasions when limitations of personnel or equipment may require a single-altimeter survey. In this case, take a reading at a benchmark. If the two benchmark altimeter readings vary by more than a few feet, repeat the sequence; in any case, it is preferable to take a series of readings and use the average elevation difference in determining the elevation of the field point.

6.2.9 There are recording altimeters available which reduce the manpower demands of the single-or two-base surveys. A recording micro barograph is also very useful on a field survey to obtain a continuous record of the pressure variations related to diurnal effects or moving pressure systems; with the aid of this record one can eliminate or recheck observations made during periods of rapidly changing pressure, or even correct field observations for the dynamic pressure component.

Observer J. Porter

Date 10 Sept. 71

(1) Upper Base Station Elevation 1000 (Location) B. M. 2-Longhill

(2) Lower Base Station Elevation 400 (Location) Airport Runway 6

(3) Difference (1 - 2) 600

(4) Altimeter Reading, Upper Base 1200

(5) Altimeter Reading, Lower Base 500

(6) Difference (4 - 5) 700

	Site # A	Site # B	Site # C	
(7) Altimeter Reading; Field Site	800	570		
(8) Altimeter Reading; Lower Base	500	500	500	
(9) Difference (7 - 8)	300	70		
(10) Divide (3/6)	0.857	0.857	0.857	
(11) Multiply (10 x 9)	257.10	59.99		
(12) Elevation; Lower Base (2)	400	400	400	
(13) Elevation; Field Site (11+12)	657	460		

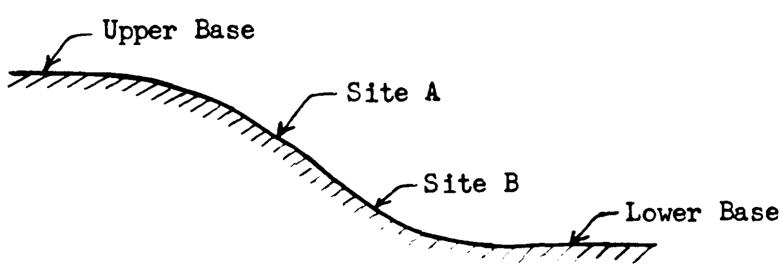


Figure 6.2-1 Two-base Altimeter Survey Computations

6.2.10 The effect of these dynamic pressure changes on survey accuracy can be significant, as shown by the following example: Between 1000 and 1200 local time, while an altimeter survey was in progress, the barograph shows a pressure fall of 0.10 inches. (Changes of this magnitude occur frequently in many parts of the world.) Using the rule-of-thumb relationship that a change in elevation of 1000 ft results in a pressure change of about one inch of mercury, a change of 0.10 inch is equivalent to an elevation difference of about 100 ft. Therefore during the 2-hour period while the survey was in progress, the dynamic pressure component was causing the equivalent of a 25-ft elevation difference (at a point) each 30 min.

6.2.11 Another source of altimetry error is related to the horizontal gradient of pressure, which is indicated by the spacing of isobars on weather maps. A survey proceeding on a line perpendicular to the isobars in the vicinity of a moderately intense storm system might incur errors on the order of 1 to 3 ft per mile, related to this horizontal difference in the pressure field. Under such circumstances, however, the surface winds could be expected to be 15 mph or more, and if the rule mentioned previously of taking surveys only during very light wind conditions is followed, the horizontal pressure gradient error should be relatively minor.

Section 6.3 OPTICAL METHODS OF CHECKING RADION-PATH OBSTRUCTIONS.

6.3.1 Introduction

6.3.1.1 Obstruction clearance, location, and elevation can be calculated from observations of lights on a tower at one end of a line-of-sight path from the other end. Binoculars are often useful for making these observations. The lights used may be sun reflection flashes, xenon tube flashes, a laser beam, or an ordinary high-intensity electric lamp. All of these sources have advantages, but the xenon flash tube seems to be the most convenient source with a long range. The flashes have the additional advantage of being easily identifiable. Xenon flashes with an effective radiated peak power of a million or more watts, can be obtained from portable equipment.

Light-ray bending through the atmosphere is about the same as for radio waves in a well-mixed atmosphere, and errors in determining radio clearance from optical measurements should not be appreciable on the normal line-of-sight paths under such conditions.

On the tower at F in figure 6.3-1, a light is located at a potential upper antenna position, D, with another light below it at B. The location of B is not critical but it must be compatible with the height of the tower at E. Also for a path with two predominate obstacles care must be taken in choosing the heights of B and C. The height of D and B above ground must be measured. The ground elevations above mean sea level, m.s.1., of sites E and F should be known as well as the distance, d, between E and F. At site E the height above ground where light D is half obstructed from view (C) is measured, also the height A where B is half obstructed.

Using the standard slope-intercept formula for a straight line, $y = mx + b$, the intersection of lines AB and CD at the obstacle

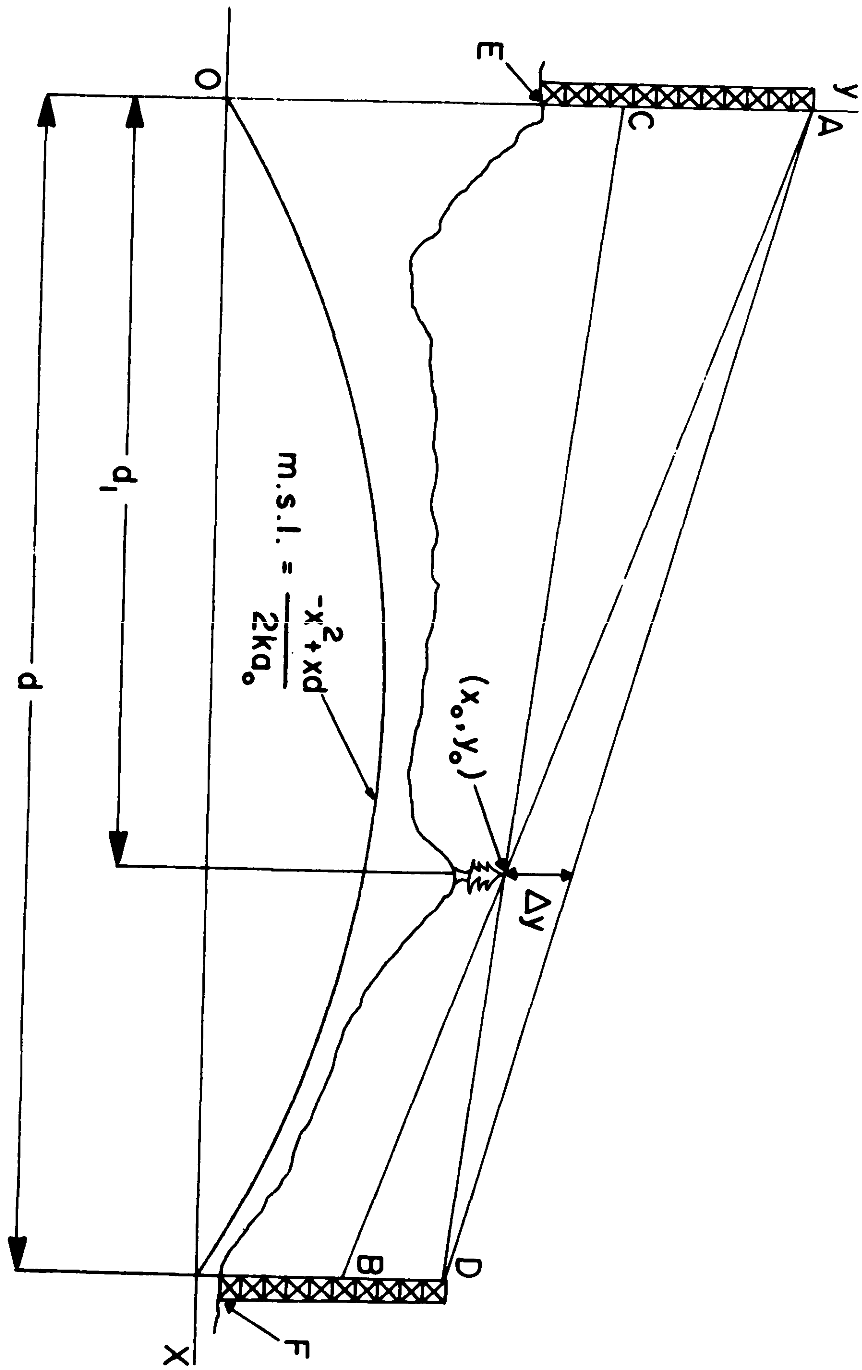


Figure 6.3-1 Calculating clearance over an obstruction using lights and binoculars.

(x_0, y_0) can be readily calculated. The difference between the value of y on the line $\overline{AD}$ at x_0 and the value of y_0 is the clearance over the obstacle for the meteorological conditions prevailing at the time when the observation of the light at D and B was made. The value, $d_1 = x_0$, should be verified using the map profile if one is available.

Using the configuration in figure 6.3-1 as an example, the distance to the obstacle, d_1; the clearance, Δy, and the height of the obstacle above m.s.1., h_0, is calculated as follows :

From the tower coordinates at E and F, the distance, d is found to be 20 km. The elevation above m.s.1. at E is 1100 m and at F it is 21 m. D was determined to be 35 m above F and B was 7 m above F. A was observed to be 41 m above E and C was 3 m above E.

The coordinates of A, B, C, and D are as follows:

$$(x_A, y_A) = (0, 1141)$$

$$(x_B, y_B) = (20000, 28)$$

$$(x_C, y_C) = (0, 1103)$$

$$(x_D, y_D) = (20000, 56).$$

$$\text{For } \overline{AB}, \quad y = \frac{28 - 1141}{20000} x + 1141 \qquad (6.3\text{-}1)$$

$$\text{For } \overline{CD}, \quad y = \frac{56 - 1103}{20000} x + 1103 \qquad (6.3\text{-}2$$

$$\text{For } \overline{AD}, \quad y = \frac{56 - 1141}{20000} x + 1141 \qquad (6.3\text{-}3)$$

or

$$\text{For } \overline{AB}, \quad y = -0.05565\, x + 1141 \qquad (6.3\text{-}1)$$

$$\text{For } \overline{CD}, \quad y = -0.05235\, x + 1103 \qquad (6.3\text{-}2)$$

$$\text{For } \overline{AD}, \quad y = -0.05425\, x + 1141 \qquad (6.3\text{-}3)$$

Subtracting eq. 6.3-2 from eq. 6.3-1,

$$0.0033\ x_o = 38$$

$$d_1 = x_o = 11{,}515.1 \text{ m}$$

$$y_o = 500.2 \text{ m}$$

For $\overline{AD}$ at x_o,

$$y = -624.69 + 1141$$

$$y = 516.31 \text{ m.}$$

Then Δy = 516.31 - 500.2 = 16.1 m.
For m.s.1. at x_o assuming k=4/3, from figure 6.3-1 and paragraph 4.2.15.2

$$y = \frac{-x_o^2 + x_o d}{2\ k\ a_o}$$

Substituting for the example,

$$y = \frac{-132{,}597{,}528+230{,}320{,}000}{(2)\ (4/3)(6{,}370{,}000)} = 5.6\text{m.}$$

Then h_o = 500.2 -5.6 =494.6 m. Note that six place accuracy should be used in some of these calculations.

Methods for determining clearance by measuring elevation angles from the obstruction itself are available but these methods have the disadvantage that it is often difficult to orient yourself in the area where the obstacle is located and many times the obstacle is relatively inaccessible.

Section 6.4 EQUIPMENT, TOWERS, CALIBRATIONS, AND TEST PROCEDURES FOR PATH LOSS MEASUREMENTS.

6.4.1 Introduction

6.4.1.1 Path-testing of a radio route is a large and expensive operation, which must be carefully organized and well run to get the best results. Temporary test-towers must be set up at each proposed repeater site, with the radio transmitter at one end of a path and the receiver at the other. Height-loss curves are obtained for each path and analyzed before moving to the next path. The transmitter T and receiver R leap-frog along the route, and while one path is being tested, the construction crew erects the next test tower. The requirements for equipment, towers, crew, etc., are discussed in more detail below.

6.4.2 Characteristics of the radio equipment

6.4.2.1 The main requirements of a test system to be used for path-testing are accuracy, reliability, portability, weatherproof operation, and ease and convenience of operation. It must also be packaged for mounting on an antenna carriage) and so must be lightweight. For extra convenience and ease of operation, the power and control units of the microwave equipment are often mounted in trucks with specially built bodies. They can then be removed easily for testing from roof tops or inaccessible locations.

6.4.3 Typical test link

6.4.3.1 There are several different types of equipment available, operating in the 4 and 8 GHz bands. The transmitter and receiver are packaged in weather proof units mounted on the rear of parabolic dish antennas. These antennas ride up and down the tower on antenna carriages, which run on tracks attached to the tower, or on the tower members themselves. Provision is made for tuning the test equipment over the desired frequency range, and to monitor frequency and output power. The test equipment may be powered by either battery or a.c., and all power and control voltages are carried up a control cable, to the radio-frequency units, from a control cabinet at the base of the tower. When used for path-testing, the receiver is calibrated in decibels from free-space loss, or power measured at the receiver input terminals, sometimes by means of operating from the receiver automatic gain control or an IF log-linear amplifier. The signal level is then obtained directly from the meter reading, using a calibration curve.

6.4.4 Test-towers

6.4.4.1 Before deciding on the type of test-tower to use, it is necessary to determine what height of tower is required. This has a direct bearing not only on the cost of the path-testing, but on the results obtainable. On 4 and 6 GHz routes, where the average path length is roughly 40 km, permanent towers up to 100 m are common, and longer paths or higher towers occur frequently. Figure 6.4-1 shows a typical 48.3 km path, with the profile plotted for k = 4/3. The two obstructions are also plotted for k = 2/3, plus the usual clearance for the first Fresnel-zone radius.

6.4.4.2 The heights of the tower required to give this clearance at k = 2/3 are roughly 60 m at each end, as shown. However, the area between 18 and 37 km contains potential reflecting surfaces. It is therefore desirable to search for reflections with path clearances equivalent to those occurring when k approaches infinity. The earth bulge at midpath is roughly 34 m at k = 4/3 versus zero at $k = \infty$. Hence, a test-tower 100 m high at both ends of the path is required.

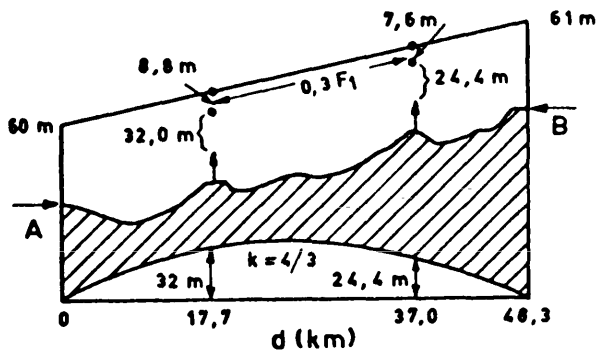


Figure 6.4-1 Required Height of Test-tower.

Experience shows that it very seldom pays to use less than 60 m. A good rule is to estimate the tower height required to measure two even zones from possible reflecting surfaces in the path. This usually means towers 100 m high.

6.4.4.3 One type of tower often used is erected from the bottom up, by inserting the next section. The sections come in either square or triangular cross -section as shown in figure 6.4-2. The sections are made of tubular metal, usually aluminum, and the corners form tracks up which the antenna carriage runs. Erection of the tower requires a crew of about 12 men and 4 to 8 hours of working time.

6.4.4.4 Another type of tower often used is a scaffolding type, available in heights up to 100 m or more. It is a guyed tower, built in sections which fold up for shipping. To erect the tower, the sections are stacked one on top of the other, being hoisted to the top with a ginpole arrangement before being bolted in place. Each 2 m section includes a platform, and stairs which zigzag up inside the tower. This makes it easy to do optical tests and to adjust the equipment. Special tracks which hook to all four sides of the tower permit the use of deep wheel flanges, thereby eliminating danger of the carriage coming off the tracks, see figure 6.4-2c.

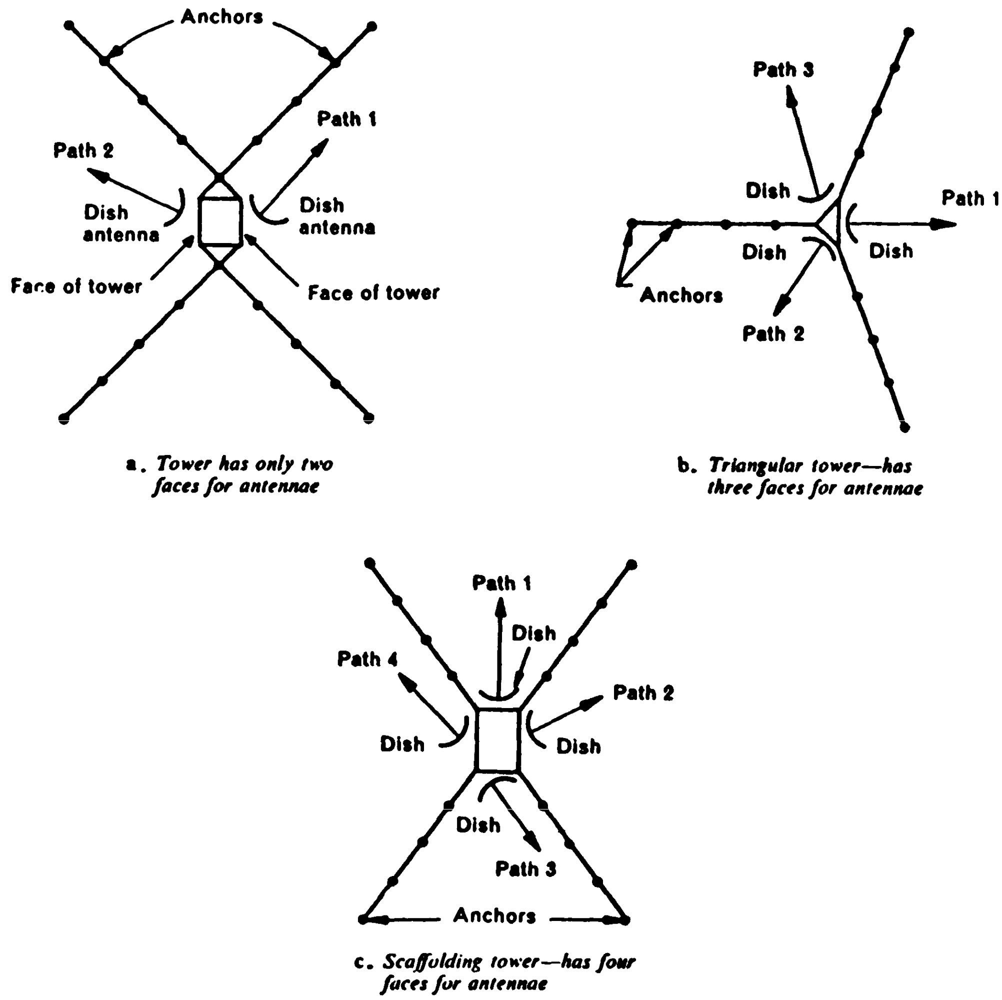


Figure 6.4-2 Orientation of Test-towers.

6.4.4.5 The erection time for this tower is approximately 8 hours, with a crew of four to eight men and a foreman.

6.4.4.6 Test paths often have one end at an existing microwave site. It is usually possible to lash the tracks to the cross members of the permanent tower. The special tracks of the scaffolding type tower can be used in the same way (they may require extra cross pieces mounted temporarily on the existing tower).

6.4.4.7 The tower shown in figure 6.4.2a gives a coverage using two antenna carriages on opposite faces of the tower. However, because the path bearings are seldom 180° apart, it is often difficult to orient the tower correctly. Local conditions may limit the choice of suitable anchor locations and correct orientation of the tower must be decided on the spot. This is not a problem with the triangular tower (three faces) or the scaffolding tower (four faces). Path bearings should be marked with stakes. Anchor locations should also be staked.

6.4.4.8 The test-tower must be erected on the same spot as the permanent tower, so the proper spot must be agreed on before testing begins. The test site should be marked by iron stakes, and a plot plan should show measurements to prominent features of the terrain. The exact location will then not be lost if the stakes are disturbed. If these precautions are not taken, the permanent tower may easily be located to one side of the test path, resulting in extra obstruction height and a poor or unworkable path. The time and money spent on path-testing can be completely wasted if these precautions are not taken.

6.4.4.9 A second precaution must be taken, i.e., allowance must be made for changes in elevation of the site during construction. Grading or filling of the site often changes the grade level by many meters.

6.4.4.10 These changes must be allowed for when specifying antenna heights. Antenna elevations should be given, not tower heights. They can be quoted relative to an arbitrary datum set up on the site, to make sure the tower provides the correct antenna heights.

6.4.5 Associated test equipment

6.4.5.1 The test equipment listed below is typical of what may be required, depending on the type of radio equipment used for testing:

a. power meter - to measure power levels at radio frequencies;

b. signal generators - to generate radio-frequency signals;

c. waveguide and coaxial attenuators - to adjust radio-frequency power levels;

d. waveguide to coaxial transitions;

e. log-linear amplifiers;

f. microwave receiver (solid state);

g. preselector filter;

h. microwave antennas;

i. directional couplers;

j. signal-level recorders;

k. a VHF radio-link is used for talking between transmitter and receiver sites. Antennas for this system are usually ground-plane types, mounted on top of the test tower. Yagi or corner-reflection types are also used if extra gain is needed, or interference is a problem.

6.4.6 Antenna carriage

6.4.6.1 The antenna carriage is a light metal framework, designed to ride up and down the tower carrying the test antenna and the transmitter or receiver. It should have motors to adjust azimuth and elevation of the antenna by remote-control from the ground. This greatly reduces the need for manpower at the test site, and increases speed and accuracy in making tests.

6.4.6.2 The antenna carriage is raised and lowered by means of a winch. The winch fits on the tower and can be hand-powered or motor-driven. Any motor-driven winch used should be arranged to stall well before the breaking point of the cable is reached. A safety cut-off switch should be mounted on the carriage, with a suitable stop installed at the tower top. A counter weight may be helpful for hand operated height variable equipment.

6.4.7 Power requirements

6.4.7.1 The radio test equipment may be powered either by a.c. or battery, but there is sometimes a need for a.c. to charge batteries, and to operate winches, azimuth and elevation motors, radio communication equipment, tower lights, test equipment, etc. In choosing a power source, it should be noted that:

a. at high altitudes, engines often become less efficient, output drops and voltage regulation suffers, so a large capacity is needed;

b. good frequency and voltage regulation are essential. Generators must be located far enough away that noise is not a problem; the long power feeds then cause a large voltage drop;

c. accurate test results depend on well-regulated line voltage at both transmitter and receiver;

d. continuous-duty rating is required. The radio equipment should normally be left on to reduce surges and warm-up time, and prevent condensation of moisture in the equipment.

6.4.8 Licensing of radio equipment

6.4.8.1 A radio-station license is usually needed for the radio test link and the VHF radio communication link.

6.4.8.2 Approval of government agencies is necessary for each test tower erected. Data must be provided on dates of erection and dismantling of each tower, ground elevation, tower height, and latitude and longitude. Alternative sites should be approved in advance, to avoid delay in case test paths prove unsatisfactory. Licensing agencies often require painting and lighting of all towers, or those exceeding a certain elevation.

6.4.8.3 Details on local requirements should be checked with the national or other government agencies concerned.

6.4.9 Manpower requirements

6.4.9.1 Nominal requirements are one engineer, one technician and two others.

6.4.10 Calibrations:

6.4.10.1 The test receiver should be calibrated before starting tests each day and checked at intervals, as required. The transmitter output should be measured and checked periodically. Some of the small solid-state microwave oscillators are very stable in power output.

6.4.11 Radio-frequency levels in a radio path

6.4.11.1 Figure 6.4-3 illustrates the variation in level of the radio-frequency signal over a typical microwave path. The free-space path loss is actually the loss between antennas, but the calibration technique must simulate the signal arriving at the receiver converter. The technique of doing this is described below, for a typical test link operating at a frequency of 4 GHz.

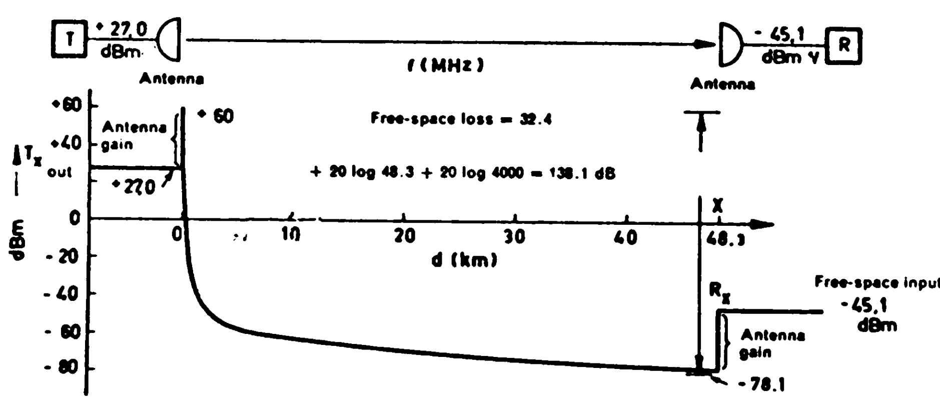


Figure 6.4-3 Levels of the Radio-frequency in a Radio Path.

6.4.12 Typical calibration procedure

6.4.12.1 The equipment should be allowed to warm up for stable operation (a minimum of 30 min). The transmitter is then tuned to the desired test frequency, the output is measured and recorded in the log book.

6.4.12.2 The receiver should be carefully aligned and tuned to the test frequency. The free-space path loss is then calculated for that frequency, for the particular path length. The theoretical free-space input signal at the receiver can then be calculated by subtracting the sum of antenna gains and transmitter output from the free-space loss. This is the level at the point X in figure 6.4-3, and is the level that must be simulated by the calibration procedure.

6.4.12.3 Figure 6.4-4 is a block diagram illustrating how the automatic gain-control meter of the receiver is calibrated to read the radio-frequency signal strength. Either a log-linear IF amplifier or automatic gain control voltage may be used to drive the recorders. The signal-strength recorder should be connected and calibrated at the same time as the signal-level meter.

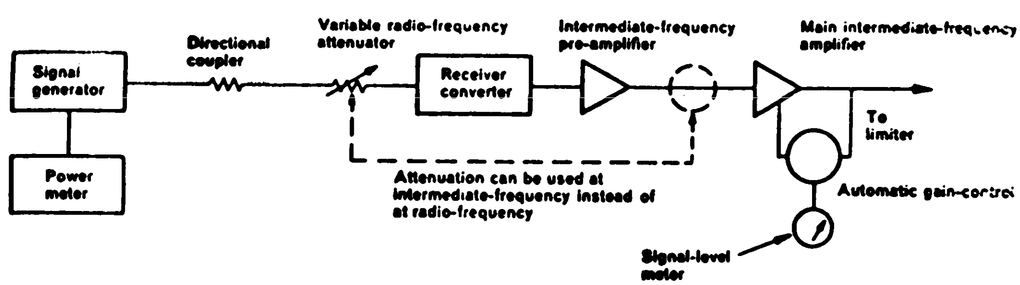


Figure 6.4-4 Block Diagram of the Method of Calibrating the Automatic-gain-control Meter.

6.4.12.4 In the calibration procedure, the signal generator feeds a signal at the test frequency into the receiver converter. The total loss of the directional coupler and variable attenuator, and the signal generator output, are adjusted to give the desired free-space input to the receiver. Changing this level in steps of 1 dB (by means of the variable attenuator) and noting the reading on the signal-level meter will give a calibration curve as in figure 6.4-5. (It is, of course, possible to eliminate the variable attenuator if the output of the signal generator is easily adjustable in 1 dB steps).

6.4.12.5 The signal-level indication is usually adjusted so that the free-space level falls on the most linear part of the calibration curve, as shown in the typical curve in figure 6.4-5.

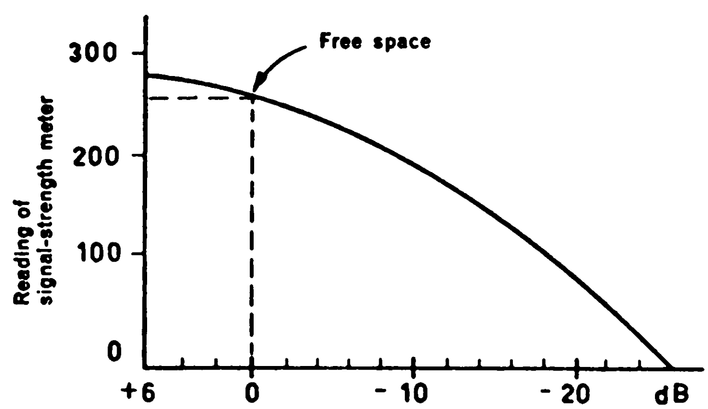


Figure 6.4-5 Typical Calibration Curve

6.4.13 Sample calculation

6.4.13.1 The signal generator output required to simulate the free-space level at the receiver input is calculated as in the following example.

For a path 48.3 km long and a test frequency of 4 GHz:

Transmitter output (0.5 W)	= +27.0	dBm
Antenna gain (two 1.5 m dishes)	= 66	dBm
	+93	
Free-space path loss (32.4 + 20 log 48.3 + 20 log 4000)	= -138.1	dB
Free-space receiver input	= -45.1	dBm

This is the level to be simulated by the signal generator and attenuators, as follows:

Directional coupler loss (at 4 GHz)	= 44	dB
Variable attenuator setting	= 6.0	dB
Total loss	= 50	dB
Signal generator output to give -45.1 dBm	= +4.9	dBm

6.4.13.2 The variable attenuator is set at 6 dB or more, so that levels above free space can be simulated by reducing the attenuator setting.

6.4.14 Calibration errors

6.4.14.1 The calibration must be as accurate as possible, as errors will be reflected in the test results. Some common errors are:

a. errors in variable attenuator settings: each attenuator should have its own calibration curve and should be checked periodically;

b. line voltage variations: the line voltage at the receiver, especially, should be well regulated. A change of 1 V can easily cause the free-space level to vary up or down by 1 dB or more;

c. losses in directional couplers and fixed attenuators: each should have its own calibration curve of loss as a function of frequency and be checked periodically;

d. accuracy and stability in the radio-frequency signal generator and power meter; these instruments should be well sheltered from wind and temperature changes, and operated from a stable supply voltage;

e. equipment troubles: the microwave equipment must be in good condition and operated by trained personnel;

f. antenna pointing: the full gain of the antennas (the value used in calculations) must be realized.

6.4.15 Suggested test procedure:

6.4.15.1 Height-loss tests:

a. Transmitter antenna fixed at one height and the receiver raised or lowered in steps.

b. Receiver antenna fixed and transmitter antenna varied in steps.

6.4.15.2 All runs should be numbered in sequence; this helps to identify changes in k, or in calibration of the equipment.

6.4.15.3 The transmitter antenna is oriented on instructions from the receiver operator, using the VHF radio for communication. The antenna heights and signal levels are recorded and immediately plotted. The antennas are usually raised in steps of 0.5 m and oriented for maximum signal at each step; the highest reading obtained at each setting is the one recorded. It is very important to locate all points at which the height-loss curve reaches the free-space level, maxima, and minima.

6.4.16 Suggested sequence of tests

6.4.16.1 Upon completion of the first run, the height-loss curve should be examined, in conjunction with the profile, to determine what the next run should be. Each test should be done twice to insure repeatability. The test sequence should minimize unnecessary movement, and the tests should be designed to obtain as much information with as few tests as possible. The tests should be performed by, or supervised by, an experienced man, to ensure best results. The test sequence below is intended only as a guide; the results of one test will suggest subsequent tests designed to get the desired information. One test can often be set up to give data on both obstructions and reflections, thereby reducing the number of tests needed. Make sure of having one a and one b run with fixed antenna heights at, or close to, the proposed final heights. Repeat certain runs during the day, as a check on k and on calibration. If tests run two days, repeat at least one run from day to day. Repeat those tests which best define an obstruction or reflecting surface near the middle of the path, where changes in k will show up the most.

6.4.17 Worst combinations of antenna heights

6.4.17.1 Once a reflection has been located, the effect of different combinations of antenna height should be investigated. This is done by lowering one antenna and raising the other, to maintain the same path clearance. There are two reasons for doing this:

a. it may be possible to find a range of antenna heights for which the reflections are less severe;

b. it is usually possible to locate one combination for which the reflection is much more severe. This also gives a better indication of the true reflection coefficient, and indicates the worst condition to be expected when the path becomes part of a working system.

6.4.18 Test frequency

6.4.18.1 It is usually better to use a test frequency in the same band as the proposed communications link. It is also possible to test a path at, say, 6 GHz, when it is intended to operate the link at 4 GHz. Proper allowance must be made for antenna patterns when analyzing test results, and to allow the proper clearance at the working frequency.

6.4.19 Signal-level recording

6.4.19.1 It may be desirable to obtain recordings of signal-level variations on the test paths. These are far from conclusive but do give some indication of propagation conditions over the paths. On difficult paths, it may also be desirable to obtain long-term records of fading.

section 6.5 PATH LOSS CALCULATIONS FOR SINGLE KNIFE EDGE DIFFRACTION LINES.

6.5.1 Introduction.

6.5.1.1 Although the primary objective of this handbook is to provide engineering guidelines for the design of microwave line-of-sight communication links, information relating to performance estimates for obstructed links is occasionally required when terrain obstacles blocking the line of sight cannot be avoided by relocating terminal or relay sites. In most cases of interest to the microwave system designer the obstruction can be represented by a single knife edge (ideally, an infinite half-plane). The methods and procedures in Section 6.5 for long-term median transmission loss calculations are generally applicable to links operating at frequencies above approximately 5 GHz and up to 100 km long. Problems involving diffraction over smooth earth or over irregular terrain not representable by a knife edge are treated in MIL-HDBK-417 on transhorizon microwave system design. MIL-HDBK-417 should also be consulted for knife-edge diffraction calculations at frequencies below 5 GHz, and for long-term transmission loss variability estimates for paths longer than 50 km.

6.5.1.2 MIL-HDBK-417 includes detailed discussion of diffraction mechanisms, derivation of the equations used, and extensive references. *For* the purposes of the line-of-sight system designer who encounters an obstructed link only occasionally, it will suffice to provide the required formulas and graphs in terms of step-by-step procedures. The user is referred to MIL-HDBK-417 for detailed explanations, references, and other background material. References to appropriate sections or paragraphs in MIL-HDBK-417 will be provided in addition to cross references to material in the earlier chapters of this handbook.

6.5.1.3 Section 6.5 includes determination of applicable atmospheric and terrain parameters (sections 6.5.2 and 6.5.3) , diffraction attenuation calculations for an ideal isolated knife edge without ground reflections (section 6.5.4), effects of qround reflections (section 6.5.5) , and effects of rounding of the knife edge on the attenuation (section 6.5.6).

A brief discussion of fading and long-term variability will be included as section 6.5.7.

6.5.1.4 Effects of power fading due to diffraction over the earth's surface when insufficient path clearance exists because of subrefractive atmospheric conditions were discussed in section 4.4.12 of this handbook. The material in Section 6.5 is also applicable to cases where a single knife edge-like obstruction may protrude into the radio path when the refractivity gradient becomes highly positive, i.e., under subrefractive atmospheric conditions.

6.5.2 Required Atmospheric Parameters (See corresponding section in MIL-HDBK-417.)

6.5.2.1 Path geometry for a single knife-edge diffraction link is usually based on an effective earth radius, a, corresponding to average atmospheric conditions characterized by a mean surface refractivity $\bar{N}_s$. In cases where the obstructing obstacle appears only for extreme subrefractive conditions (characterized by positive refractivity gradients and effective earth radius factor values k that are less than 4/3), appropriate values for the effective earth radius, a, may be determined as a function of the refractivity gradient $\Delta N/\Delta h$. This may be associated with the long-term distributions of refractivity gradients such as estimated for a particular location from [39] or [100].

6.5.2.2 Figure 6.5-1 is a map for determining the average sea-level surface refractivity $\overline{N}_0$. The next step is determining the surface refractivity as a function of path elevation:

$$\overline{N}_s = \overline{N}_0 \exp(-0.1057\, h_s) \qquad (6.5\text{-}1)$$

where h_s is the elevation of the diffracting obstacle above mean sea level in km unless either or both antenna site elevations are 0.15 km (150 m) or more below h_s. If one of the antenna site elevations e_{s1} or e_{s2} meets this criterion it is substituted for h_s and two values of $\overline{N}_s$ are calculated using (6.5-1); the desired value of average surface refractivity is the arithmetic mean of the two values determined in this manner. If both antenna site elevations are 150 m or more below the diffracting obstacle, e_{s1} and e_{s2} are both used and the obstacle height is ignored. The antenna site elevations e_{s1} and e_{s2} must also be in km. h_s, e_{s1}, and e_{s2} will also be defined in section 6.5.3.

6.5.2.3 The average effective earth radius factor, k, is related to $\overline{N}_s$ by the relation

$$a = a_0[1 - 0.04665 \exp(0.005577\overline{N}_s)]^{-1} \text{ km} \qquad (6.5\text{-}2)$$

where a_0 = 6370 km. This relation holds for $250 \leq \overline{N}_s \leq 400$, and is shown graphically in figure 6.5-2.

6.5.2.4 The relation between the effective earth radius factor k and the refractivity gradient $\Delta N/\Delta h$ in N-units per kilometer is

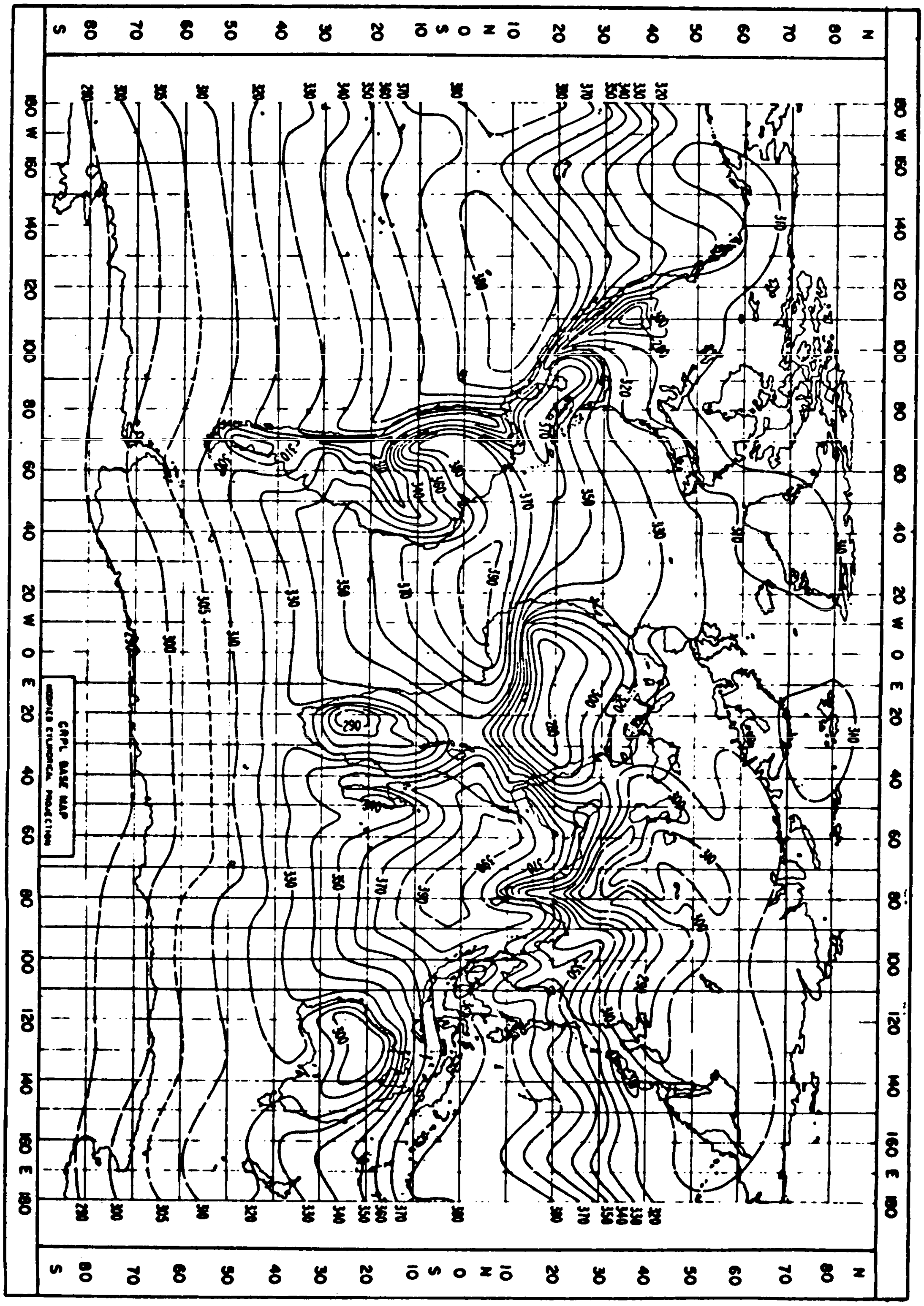


Figure 6.5-1 Minimum Monthly Mean Surface Refractivity Values, $\bar{N}_o$, Referred to Sea Level.

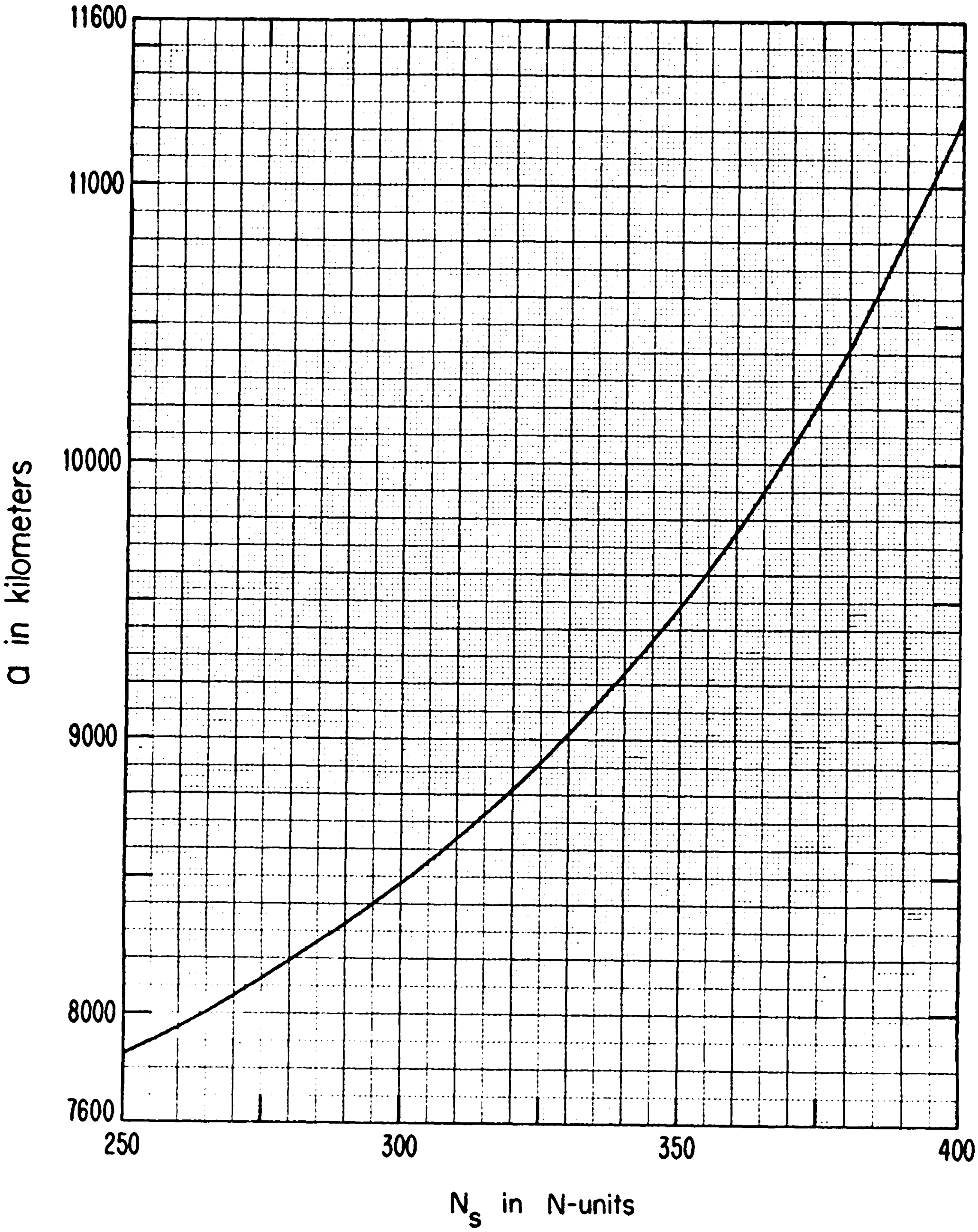


Figure 6.5-2 Effective Earth's Radius, a, versus Surface Refractivity, N_s.

qiven in figure 4.4-4 of this handbook. The effective earth radius, a, is then determined by:

$$a = Ka_o \text{ km} \qquad (6.5\text{-}3)$$

where a_o = 6370 km as before.

6.5.2.5 The procedure in paragraph 6.5.2.2 above should be used when a knife-edge diffraction path exists under average atmospheric conditions, and long-term median values of transmission loss are desired. The methods in paragraph 6.5.2.4 for determining the effective earth radius as a function of the refractivity gradient will be useful when the obstruction appears only for a small percentage of time; if the time distribution of $\Delta N/\Delta h$ can be estimated from [39] or [100], calculated transmission loss values can then be directly associated with percent-of-time values. This will be discussed further in paragraphs 6.5.7.3 and 6.5.7.4.

6.5.3 Required Terrain Parameters (See corresponding section in MIL-HDBK-417.)

6.5.3.1 Terrain parameters required for knife-edge diffraction calculations are as follows:

a. The path distance, d, in kilometers which is determined from the great-circle calculations described in section 4.2.16 of this handbook.

b. The antenna heights (center of antenna feed) above ground h_{g1} and h_{g2}, in kilometers, from system specifications or engineering assumptions.

c. The elevation of the antenna sites in kilometers above mean sea level, e_{s1} and e_{s2}, from maps or surveys.

d. The heights of the antennas (center of antenna feed) above mean sea level, h_{s1} and h_{s2} in kilometers, are:

$$h_{s1} = e_{s1} + h_{g1} \text{ km} \qquad (6.5\text{-}4a)$$

$$h_{s2} = e_{s1} + h_{g2} \text{ km} \qquad (6.5\text{-}4b)$$

h_{sl} and h_{s2} should not be confused with the parameters h_s used in (6.5-1), which refers to the elevation of the diffracting obstacle.

e. The distances d_{L1} and d_{L2} from the antenna sites to the diffracting obstacle (in kilometers) are obtained from the path profiles.

f. The elevation of the diffracting obstacle above mean sea level, h_s, in kilometers.

g. The horizon take-off angles, θ_{e1} and θ_{e2}, in radians, given by:

$$\theta_{el} = \frac{h_s - h_{sl}}{d_{L1}} - \frac{d_{L1}}{2a} \text{ radians} \qquad (6.5\text{-}4a)$$

$$\theta_{e2} = \frac{h_s - h_{s2}}{d_{L2}} - \frac{d_{L2}}{2a} \text{ radians} \qquad (6.6\text{-}4b)$$

h. The angles α_o and β_o in radians, given by:

$$\alpha_o = \frac{d}{2a} + \theta_{el} + \frac{h_{sl} - h_{s2}}{d} \text{ radians} \qquad (6.5\text{-}5a)$$

$$\beta_o = \frac{d}{2a} + \theta_{e2} - \frac{h_{sl} - h_{s2}}{d} \text{ radians} \qquad (6.5\text{-}5b)$$

i. The angular distance, θ, in radians, which is simply the sum of α_o and β_o.

j. The width of the diffracting obstacle, D_s, used as a parameter to estimate the additional attenuation due to the departure of the obstacle from an ideal knife-edge. It is usually negligible compared to the horizon distances d_{L1} and d_{L2} so that the total path distance, d, can be approximated by the sum of d_{L1} and d_{L2} even if there is significant rounding of the diffracting obstacle.

k. The effective antenna heights, h_{e1} and h_{e2}, in kilometers. These are estimated from the terrain profiles relative to a potential reflecting surface between the antenna site and its radio horizon. For smooth ground or water surfaces they are simply the antenna heights above the surface including the height of buildings, cliffs, or isolated peaks where the antenna might be located. For irregular terrain, the designer should estimate the position of an average reflecting surface through the terrain, and determine the antenna heights relative to that surface. Note that exact values for effective antenna heights are not required; therefore, rough estimates are usually sufficient. The effective antenna heights h_{e1} and h_{e2} are required in the calculation of single-obstacle diffraction attenuation (sec. 6.5.5) in cases where the ray paths are not isolated from the terrain.

6.5.4 <u>Attenuation Over Isolated Diffracting Ideal Knife Edge</u>

(See section on "Attenuation over single-horizon diffraction links" in MIL-HDBK-417.)

6.5.4.1 The attenuation relative to free space basic transmission loss (see section 4.2.21) for links which have a single obstacle as a common (or nearly common) horizon will be denoted by A_k. It is calculated as a function of the carrier frequency and several terrain parameters. The obstacle may be considered to be an ideal knife-edge if its width at the top is a few tens of inters, or less, such as a sharp mountain ridge. For rounded, or flat-topped ridges, an allowance can be made for the additional attenuation introduced by rounding as a function of D_s, the distance between the two radio horizons (see section 6.5.6).

6.5.4.2 The attenuation A_k over a diffracting obstacle is given most generally by:

$$A_k = A(v,\rho) - G(\bar{h}_1) - G(\bar{h}_2). \qquad (6.5\text{-}6)$$

The height gain fucntions $G(\bar{h}_{1,2})$ are estimates of the effects of ground reflections from the terrain between an antenna and its radio horizon. They should be used when more than half of the terrain between an antenna and its radio horizon is intersected by a first Fresnel zone ellipse in the great circle plane containing the propagation path which has the antenna and its horizon as the foci, and methods for their estimation will be given in section 6.5.5.

For the ideal knife-edge, the parameter ρ in (6.5-6) is assumed to be zero. Then, the attenuation $A(v,\rho)$ is only a function of the parameter v given by:

$$v = 2.583\ \theta\sqrt{f\ d_{L1} d_{L2}/d} \qquad (6.\ 5\text{-}7)$$

where θ is in radians, the frequency f is in MHz, and all distances are in kilometers (see section 6.5.3). This expression holds strictly only for $\theta \leq 10°$, but this value will rarely be exceeded in practical applications. When the obstacle does not intrude into the ray path, v is negative, but can still have an effect on path attenuation.

6.5.4.3 The attenuation relative to free-space basic transmission loss for an ideal knife-edge, A(v, 0), is plotted versus v in figure 6.5-3. A useful asymptotic expression for $v \geq 3$ is:

$$A(v, 0) = 12.953 + 20 \log v \text{ dB.} \qquad (6.5\text{-}8)$$

6.5.5 Effects of Ground Reflections (See corresponding paragraphs of section on "Attenuation over single-horizon diffraction links" in MIL-HDBK-417.)

6.5.5.1 As noted in paragraph 6.5.4.1, the height gain functions $G(\bar{h}_{1,2})$ in (6.5-6) should be used when more than half of the terrain between the antenna and its horizon is intersected by the first Fresnel Zone ellipse. The maximum half-width of this ellipse occurs midway between the antenna and its horizon, and is given by $0.5\sqrt{\lambda d_{L1,2}}$. Here, λ is the wavelength in kilometers. It may be determined from the frequency, f, in MHz, and the free-space velocity of light, 299,790 km/sec; i.e.,

$$\lambda = (299{,}790 \times 10^{-6})/f = 0.29979/f_{MHz} \text{ km.} \qquad (6.5\text{-}9)$$

The resulting half-width is of course also in the same units; i.e., km.

For the purpose of applying this criterion, it is sufficient to sketch the ellipse on the path profile such as in worksheet 4.4-1, except that the diffracting obstacle is now used as one of the path terminals.

6.5.5.2 If not all details of the terrain profile are known, a decision regarding the use of the $G(\bar{h}_{1,2})$ functions may be made

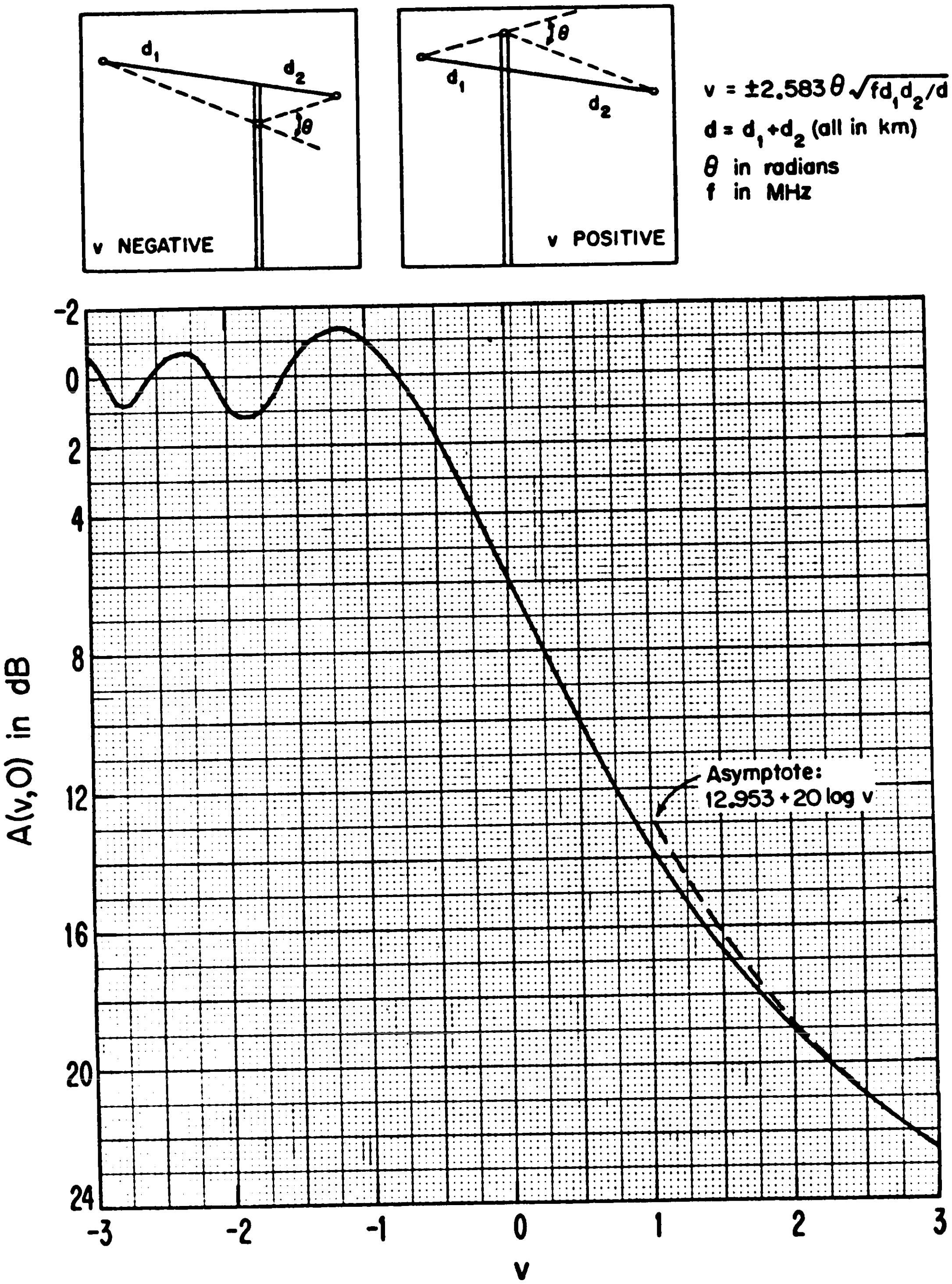


Figure 6.5-3 Knife-Edge Diffraction Loss A(v, 0) Function of the Parameter v.

on the basis of the differences in the heights between the terminal antennas and the height of the diffracting obstacle. The applicable criteria may be formulated in the following manner:

$G(\bar{h}_1) = 0$ if,

(a) both the terminal antenna height above ground h_{g1} and an estimate of the obstacle height above the terrain along the profile between terminal 1 and the obstacle are greater than $0.5\sqrt{\lambda d_{L1}}$, or

(b) $|h_s - h_{s1}| > \sqrt{\lambda d_{L1}}$

$G(\bar{h}_2) = 0$ if,

(a) both the terminal antenna height above ground h_{g2} and an estimate of the obstacle height above the terrain along the profile between terminal 2 and the obstacle are greater than $0.5\sqrt{\lambda d_{L2}}$ or

(b) $|h_s - h_{s2}| > \sqrt{\lambda d_{L2}}$.

Otherwise, $G(\bar{h}_1)$ or $G(\bar{h}_2)$, or both must be calculated using the procedures shown in the next paragraph. The parameters λ, d_{L1}, d_{L2}, h_g, h_{s1}, h_{s2}, h_{g1}, and h_{g2} in the criteria above have been defined earlier and must all be in kilometers.

6.5.5.3 A graph of $G(\bar{h}_{1,2})$ is shown in figure 6.5-4 as a function of the normalized parameter $\bar{h}_{1,2}$, and of two other parameters, κ and b, which depend on conductivity and dielectric constant associated with the terrain, on the polarization, and on the carrier frequency. In order to calculate $\bar{h}_1$ and $\bar{h}_2$, one must first determine effective radii, a_1, and a_2, as a function of the horizon distances, d_{L1} and d_{L2} and the <u>effective</u> antenna heights h_{e1} and h_{e2}, which were defined in section 6.5.3:

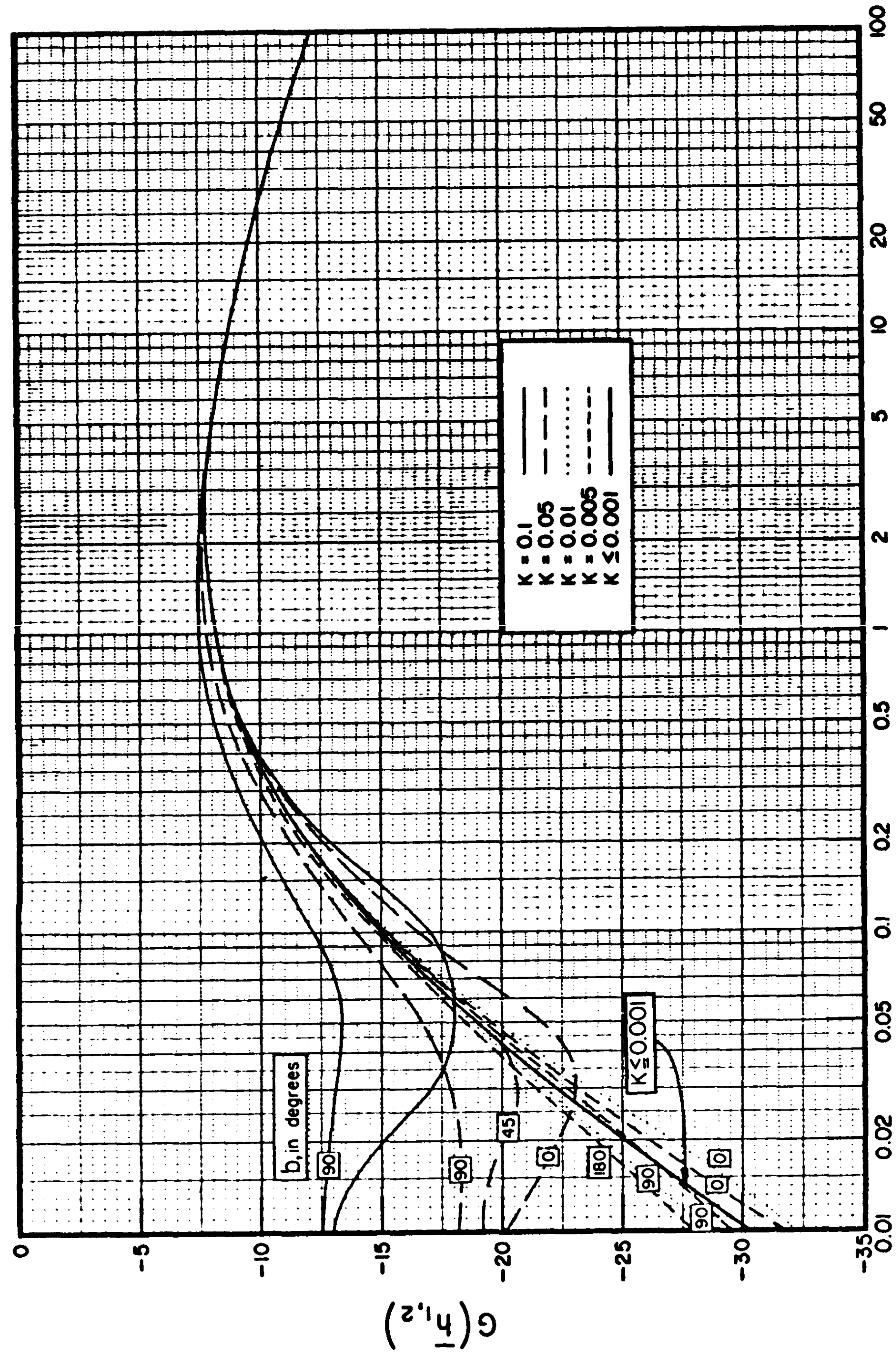


Figure 6.5-4 The Residual Height Gain Function $G(\bar{h})$.

$$a_1 = d_{L1}^2/2h_{e1} \text{ km} \qquad (6.5\text{-}10a)$$

$$a_2 = d_{L2}^2/2h_{e2} \text{ km} \qquad (6.5\text{-}10b)$$

All parameters <u>including</u> the heights must be in <u>kilometers.</u> For horizontal and vertical polarization over land or fresh water, and for horizontal polarization only over sea water, the parameters $\bar{h}_1$ and $\bar{h}_2$ may be approximated for frequencies above approximately 100 MHz by:

$$\bar{h}_1 \cong 5.74\,(f^2/a_1)^{1/3} h_{e1} \qquad (6.5\text{-}11a)$$

$$\bar{h}_2 \cong 5.74\,(f^2/a_2)^{1/3} h_{e2} \qquad (6.5\text{-}11b)$$

where $a_{1,2}$ and $h_{e1,2}$ are in kilometers, and f is in MHz. Then $G(\bar{h}_{1,2})$ in decibels is read from figure 6.5-4 using the curve marked "K $\leq$ 0.001" and substituted into (6.5-6) to obtain the diffraction attenuation A_k. Note that the $G(\bar{h}_{1,2})$ functions are negative and that the sign must be watched when substituting in (6.5-6); thus the $|G(\bar{h}_{1,2})|$ is added to the total attenuation.

6.5.5.4 The procedure described above is applicable in almost all cases of single-obstacle diffraction. In some instances, however, a communication link may use vertical polarization and extend over <u>sea water</u> with portions of land such as an island or topographic features on a peninsula forming the diffracting obstacle. Here the method for obtaining $G(\bar{h}_{1,2})$ is somewhat more complicated since for vertical polarization the parameter K is significantly greater than 0.001 and may approach 0.1 particularly at lower frequencies. Thus, K and b must be determined first from the curves shown in figures 6.5-5 and 6.5-6, respectively. They are shown versus frequency for horizontal and vertical polarization, and for various combinations of the surface constants σ (conductivity) and ϵ (dielectric constant) corresponding to poor, average, and good ground, and to sea water although for the purposes of Section 6.5 only the curves corresponding to vertical polarization and sea water are used. In figure 6.5-5, K_0 is defined for an effective earth radius a = 8500 km corresponding to the standard atmosphere with k=4/3 (see section 4.4.6). For use in the determination of $\bar{h}_{1,2}$, K_0 must be modified by the factors $C_{01,2}$. These are:

$$C_{01} = (8500/a_1)^{1/3} \qquad (6.5\text{-}12a)$$

$$C_{02} = (8500/a_2)^{1/3}, \qquad (6.5\text{-}12b)$$

where a_1 and a_2 were defined in (6.5-10) and are in kilometers. The applicable values $K_{1,2}$ are then determined by:

$$K_1 = C_{01}K_0 \qquad (6.5\text{-}13a)$$

$$K_2 = C_{02}K_2. \qquad (6.5\text{-}13b)$$

6.5.5.5 The next step is the determination of the parameters $B(K_{1,2},b)$ from figure 6.5-7 as a function of $K_{1,2}$ and of b in degrees. Then $\bar{h}_1$ and $\bar{h}_2$ are calculated from the following equations, which are used instead of (6.5-11a) and (6.5-11b):

$$\bar{h}_1 = 2.232\ B^2(K_1,b)\ (f^2/a_1)^{1/3}\ h_{e1}, \qquad (6.5\text{-}14a)$$

$$h_2 = 2.232\ B^2(K_2,b)\ (f^2/a_2)^{1/3}\ h_{e2}, \qquad (6.5\text{-}14b)$$

and $G(\bar{h}_1)$ and $G(\bar{h}_2)$ are read from figure 6.5-4 as before, but using the appropriate curve for $K_{1,2}$ and b with visual interpolation where required. Actually, (6.5-11) is a simplification of (6.5-14) for those cases where K is very small, and not a function of b to any significant extent. In (6.5-14) the distances a_1 and a_2 and the effective antenna heights h_{e1}, and

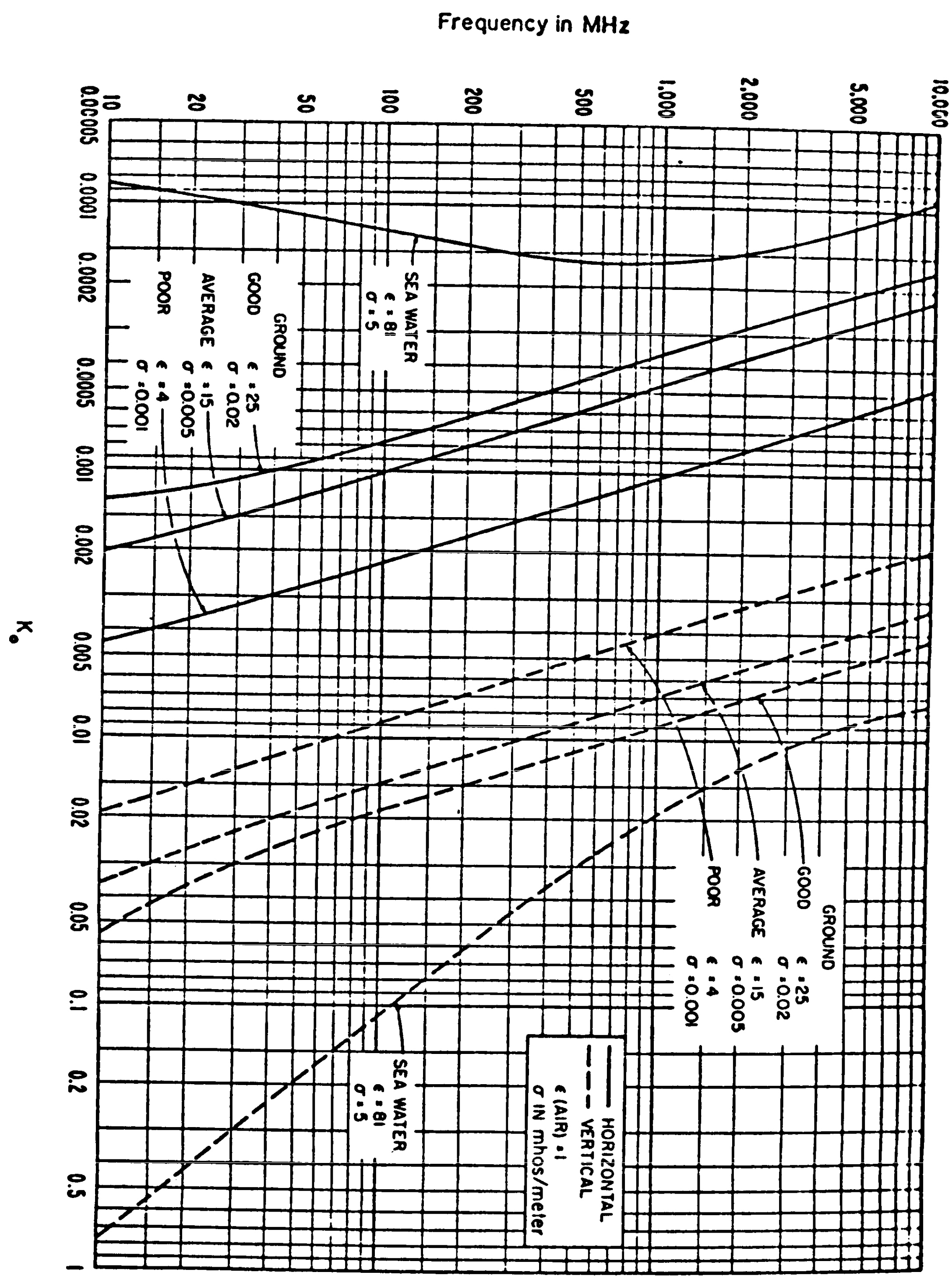


Figure 6.5-5 The Parameter K_o (for a = 8500 km).

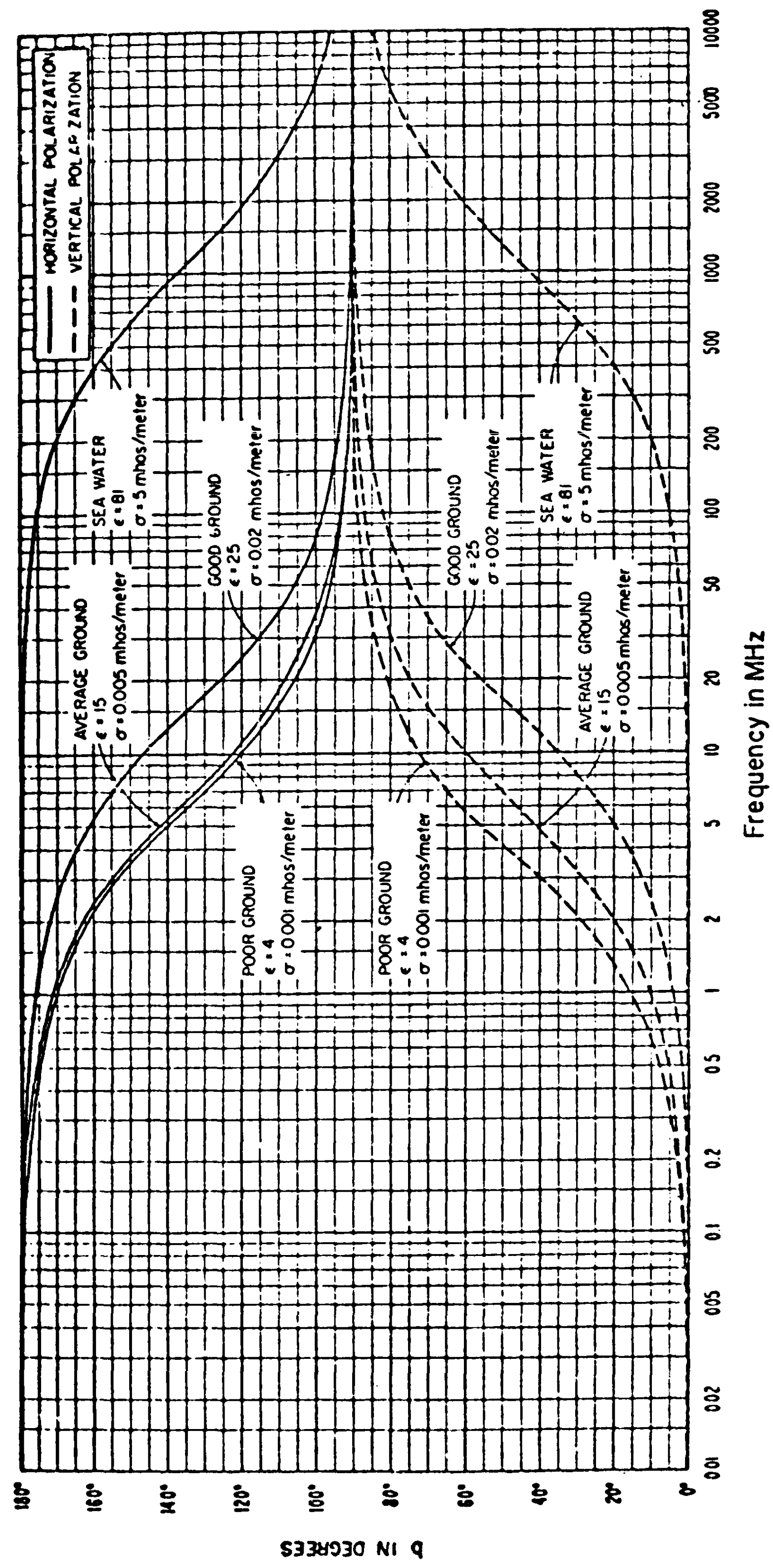


Figure 6.5-6 The Parameter b in Degrees as a Function of Carrier Frequency and Surface Constants.

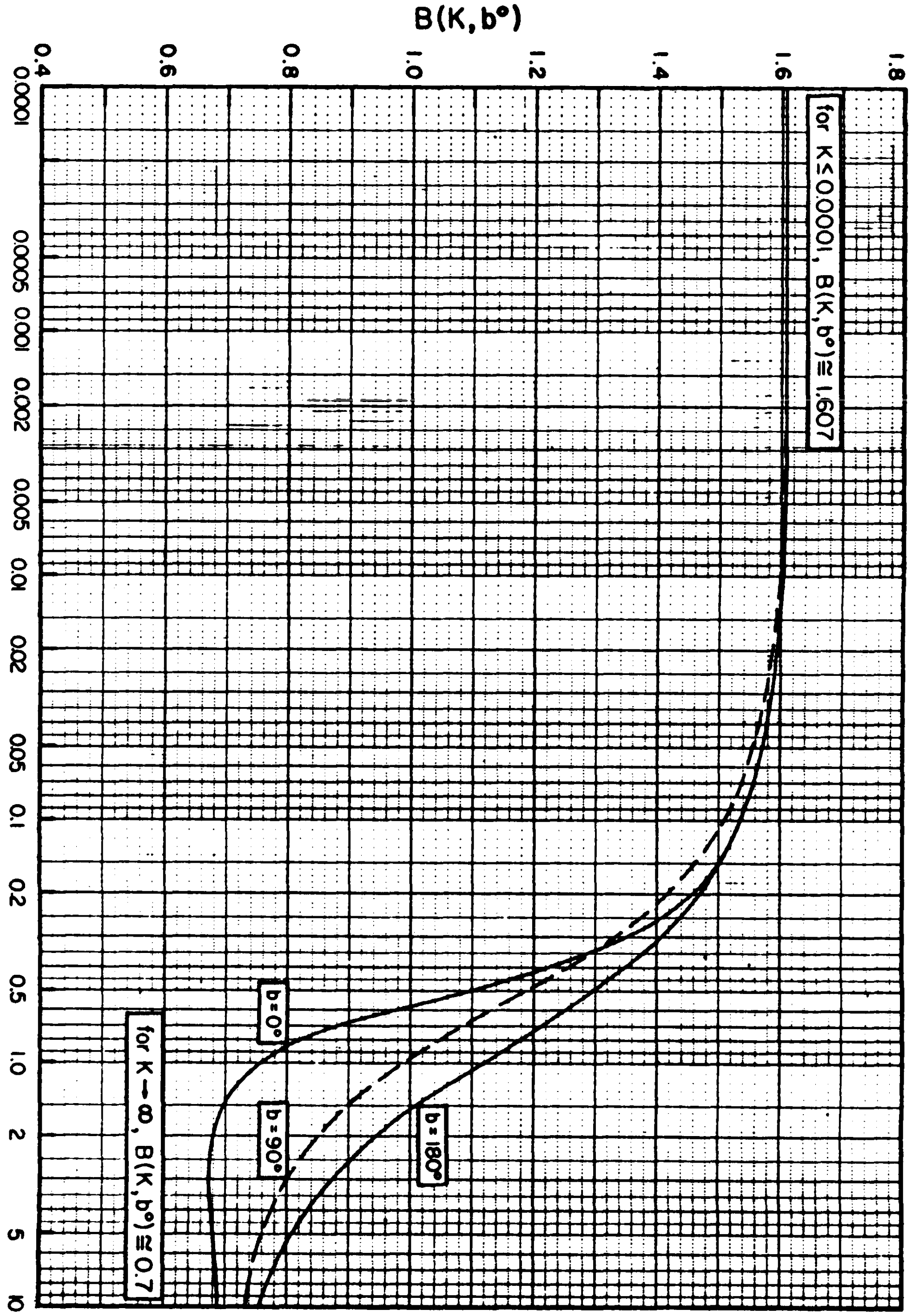


Figure 6.5-7 The Parameter B(K,b).

h_{e2} must be in kilometers and the frequency f in megahertz. If any parameter values outside the given range are encountered, the user should consult the original curves in [101] or [102]. The $G(\bar{h}_{1,2})$ values in decibels are then substituted in (6.5-6) as before to determine the attenuation A_k over the diffracting obstacle.

6.5.5.6 In cases where terrain details over the entire path are well known, and it is possible to identify pronounced reflecting surfaces, four-ray geometric optics methods may be applicable which must be modified to allow for attenuation and phase shift of each ray by the diffracting obstacle. Applicable methods and procedures for such cases are given in an appendix to MIL-HDBK-417.

6.5.6 Attenuation Over A Rounded Knife Edge (See corresponding paragraphs of section on "Attenuation over single-horizon diffraction links" in MIL-HDBK-417.)

6.5.6.1 If the diffracting obstacle cannot be approximated by an ideal knife edge; i.e., if its width at the top is more than about 30 m, attenuation calculations must take into account the rounding characterized by the parameter ρ in (6.5-6). The attenuation relative to free space can be estimated using the dashed curve on figure 6.5-8 which represents an empirical expression for mountain obstacle diffraction links, derived from available data by Nishikori, et al. [103]. It may be used to estimate $A(v,\rho)$ without having to determine the curvature or rounding of the diffracting knife edge. Note that the $A(v,\rho)$ curve in figure 6.5-8 departs from the solid curve for the ideal knife edge indicated by A(v,0) only for values of v greater than

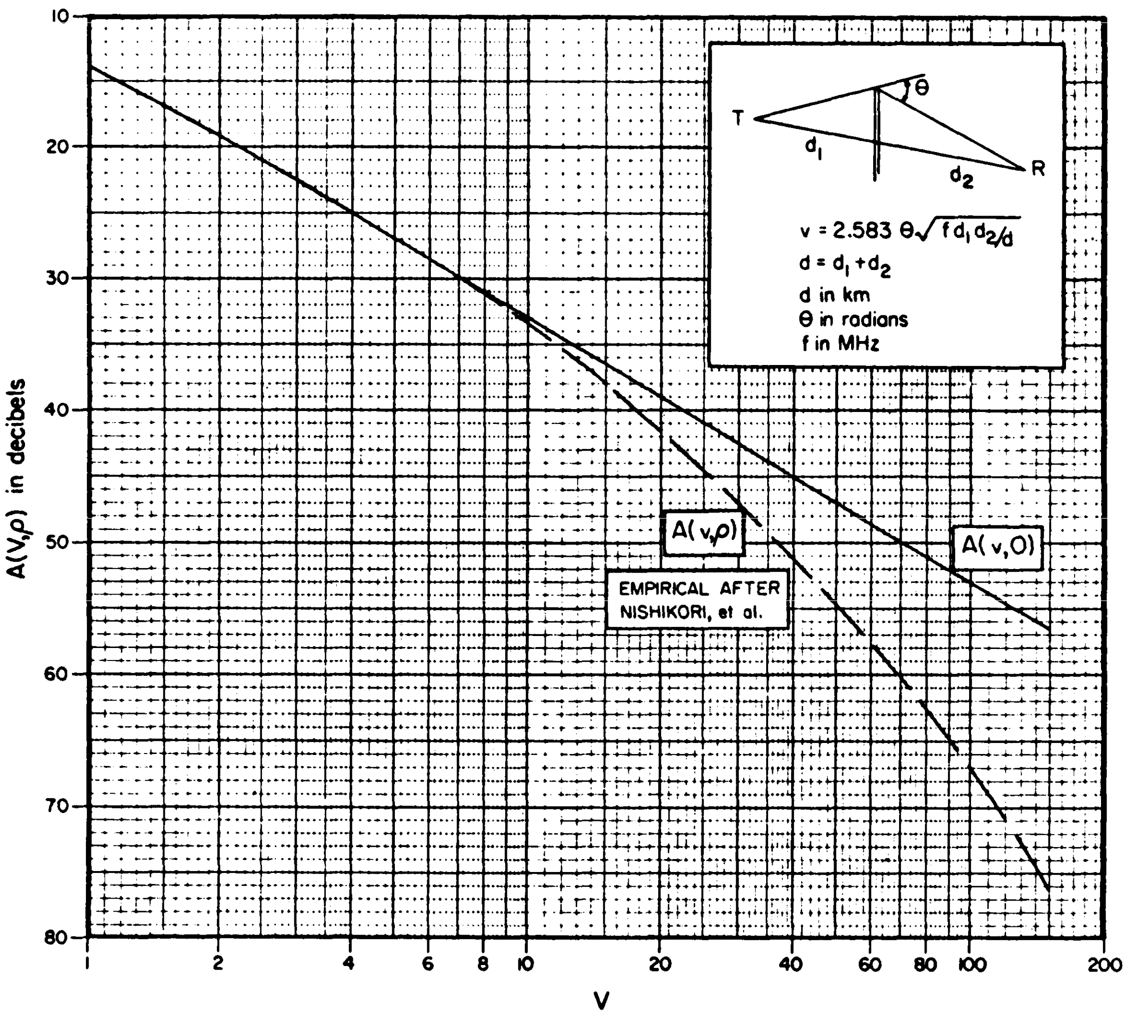


Figure 6.5-8 Empirical Obstacle Diffraction Loss.

approximately 7. The solid curve is the same as shown in figure 6.5-3 for $v \geq 1$ and given by (6.5-8) for $v \geq 3$. It is repeated here for convenience and to illustrate the effects of rounding. Note also that these effects have only been defined for $v \geq 0$; i.e., where the obstacle protrudes into the path.

6.5.6.2 In some cases it is possible to estimate the rounding of an isolated diffracting obstacle from detailed terrain profile drawings or from map studies. The attenuation $A(v,\rho)$ may then be calculated more precisely. First, the radius of curvature r of the obstacle is approximated by:

$$r = D_s/\theta, \tag{6.5-15}$$

where D_s is the distance between radio horizon (from detailed terrain profiles) in kilometers, and θ is in radians. Next, a test is made to determine whether the obstacle is isolated from the surrounding terrain using the relation:

$$kh[2/(kr)]^{1/3} >> 1. \tag{6.5-16}$$

Here, $k = 2\pi/\lambda$, r is the radius of curvature of the rounded obstacle from (6.5-15), and h is the smaller of the two values

$$\left(\sqrt{d_{L1}^2 + r^2} - r\right)$$

and

$$\left(\sqrt{d_{L2}^2 + r^2} - r\right)$$

with all distances and the wavelength λ in km. If the relation in (6.5-16) does not hold for a specific path, the methods in MIL-HDBK-417 (section on diffraction over irregular terrain) should be used. Note that the term "isolated" is used here in a different manner than in the determination of Fresnel zone clearance for applicability of the height gain functions shown in paragraph 6.5.5.2.

6.5.6.3 If the relation (6.5-16) holds, the rounding parameter, ρ, is found by calculating the product $v\rho$ using (6.5-17) below and dividing $v\rho$ by v which has been determined earlier (see equation 6.5-7). The product $v\rho$ will also be required in a subsequent step.

$$v\rho = 1.746\ \theta (fr)^{1/3}. \qquad (6.5\text{-}17)$$

Here the radio frequency f is in MHz, the radius of curvature r from (6.5-15) is in km, and the angular distance θ is in radians.

6.5.6.4 The diffraction loss $A(v,\rho)$ in decibels is plotted as a function of v for various values of ρ in figure 6.5-9. It may also be determined from:

$$A(v,\rho) = A(v,0) + A(0,\rho) + U(v\rho)\ \text{dB}, \qquad (6.5\text{-}18)$$

where the function A(v,0) is the attenuation for an ideal knife-edge $(\rho=0)$ plotted in figures 6.5-3, 6.5-8 and 6.5-9, and the functions $A(0,\rho)$ and $U(v\rho)$ are plotted in figure 6.5-10. Equation (6.5-18) is applicable under many conditions of propagation over irregular terrain between good antenna sites using either horizontal or vertical propagation. Criteria for its validity are (a) the distances d, d_1, d_2, and r must be much larger than the wavelength, λ, (b) the obstacle dimension at right angles to the propagation path must be at least the width of the first Fresnel zone, (c) the components α_0 and β_0 (see equation 6.5-5) of the diffraction angle θ must each be less than 0.175 radians, and (d) the radius of curvature, r, must be large enough so that $(\pi r/\lambda)^{1/3} >> 1$.

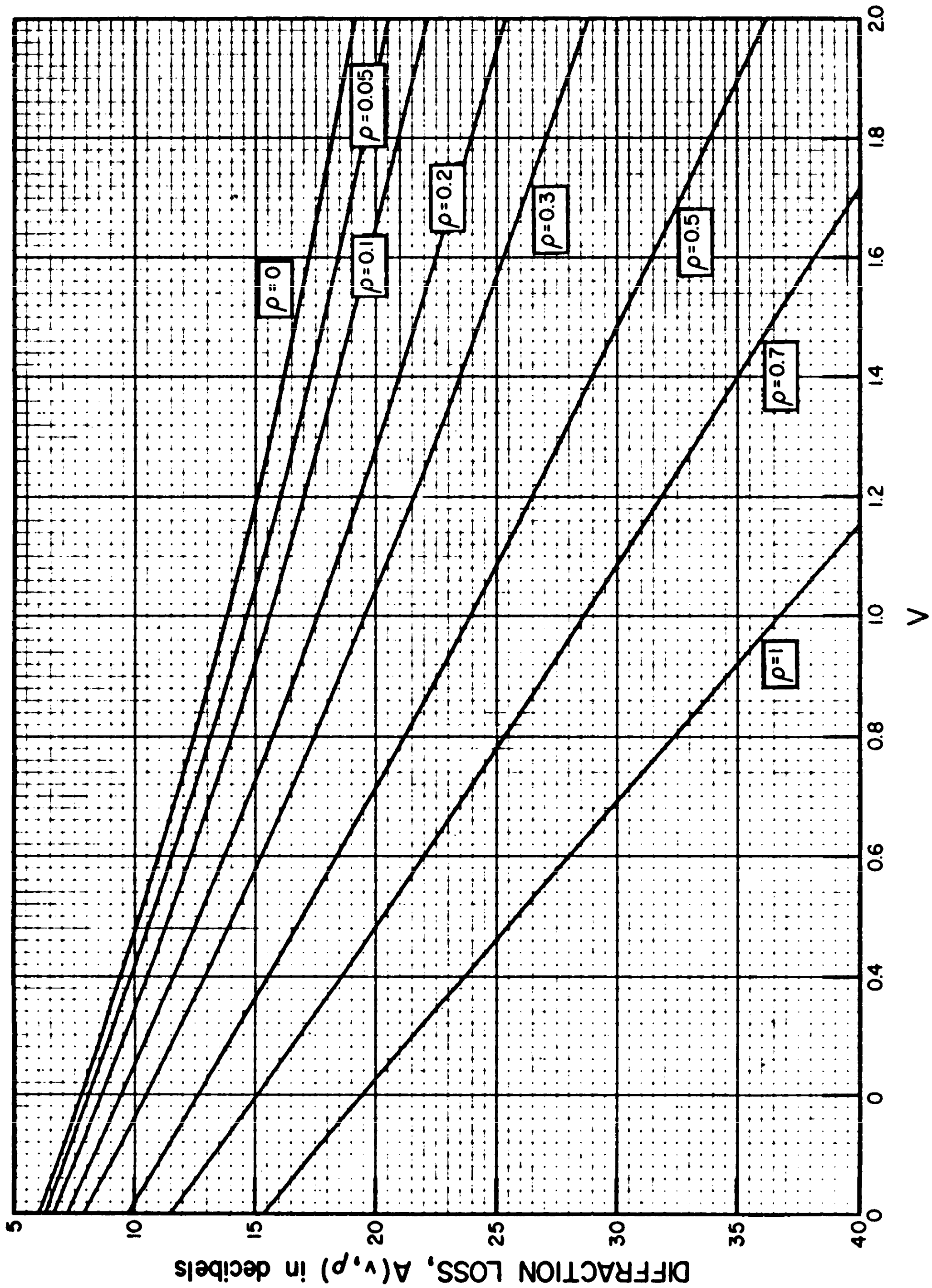


Figure 6.5-9 The Diffraction Attenuation $A(v,\rho)$ over a Rounded Obstacle.

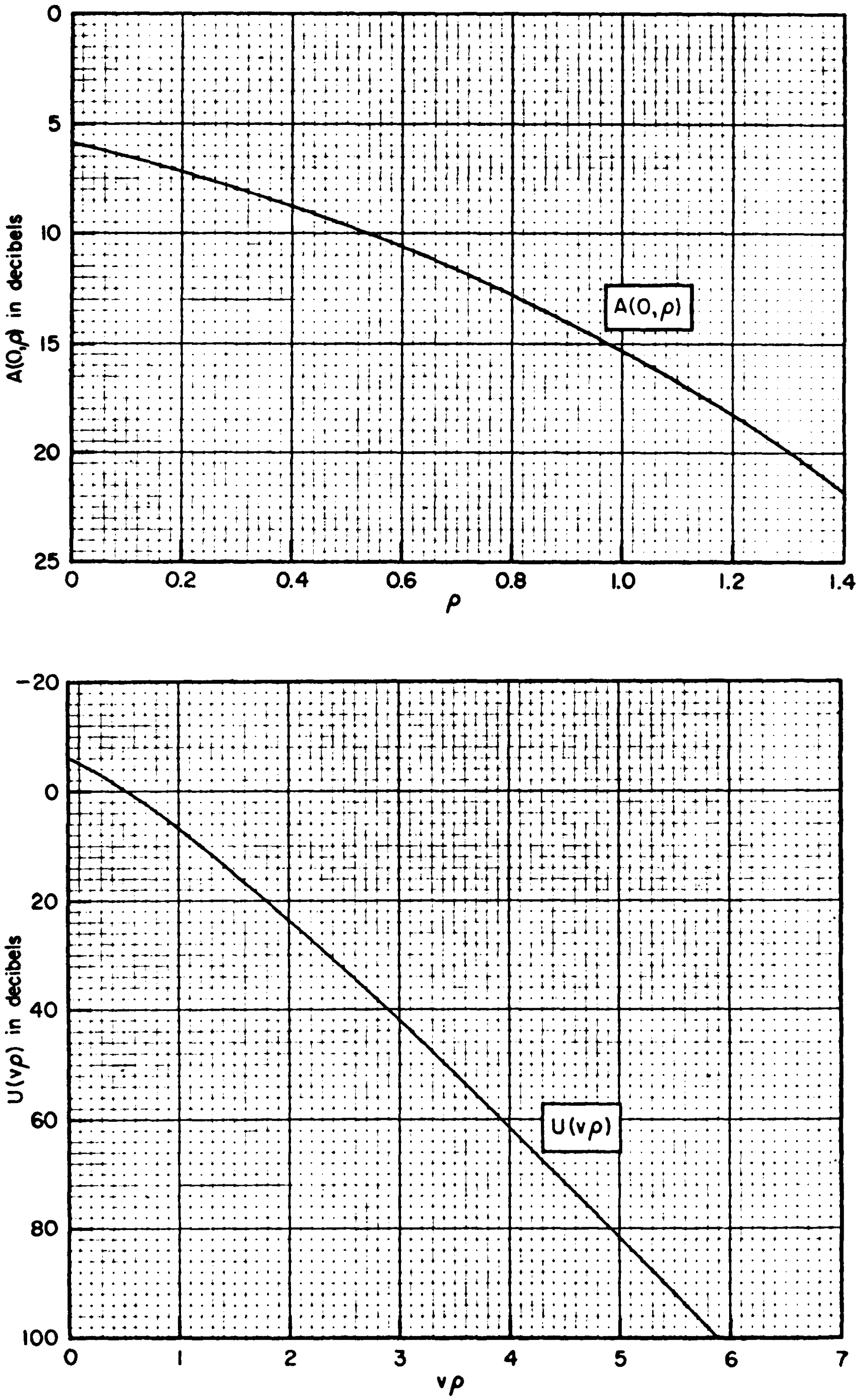


Figure 6.5-10 The Functions A (O.P) and U(vp) in Odstacle Diffraction.

6.5.6.5 In summary, the single-obstacle diffraction attenuation A_k may be obtained by calculating first the parameter v, and using figure 6.5-8 or by calculating the parameter p in addition to v and using (6.5-18): furthermore, the residual height gain functions $G(h_{1,2})$ calculated as shown in section 6.5.5 must be included where required. Values of basic transmission loss are obtained by adding A_k and the median atmospheric attenuation A_a, to the free-space loss, L_{bf}.

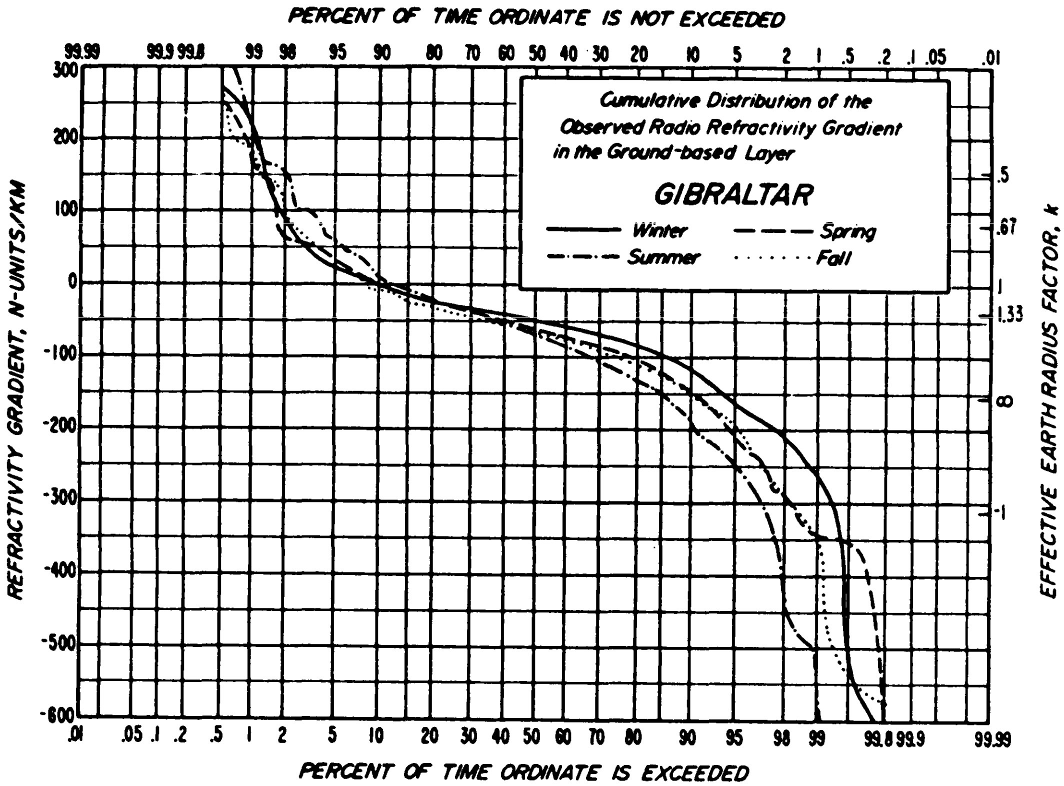
6.5.7 Fading and Long-term Variability

6.5.7.1 Fading on relatively short knife-edge diffraction links (less than about 50 km) at frequencies above 5 GHz may be assumed to be very similar in character to that discussed for line-of-sight links in sections 4.2 and 4.4 of this handbook. It is quite likely that multipath fading effects will predominate particularly when reflections from the terrain on one or both sides of the diffracting obstacle occur. Power fading due to precipitation effects can also be treated as shown in sections 4.2.23 and 4.2.24. Diffraction fading as a result of subrefractive conditions can be evaluated as shown in paragraph 6.5.7.3 below.

6.5.7.2 Long-term variability in the sense discussed in MIL-HDBK-417 is usually not of primary importance for links that are less than 50 km in length and operate at frequencies above about 5 GHz. The variability of hourly medians in such cases should not amount to more than the 3 dB corresponding to the "degraded" long-term median value used as a basis for system performance estimates in the line-of-sight case (see section 4.5.18). For longer paths, and for those at lower frequencies, the methods given in the sections on long-term variability and on service probability in MIL-HDBK-417 should be used.

6.5.7.3 As already noted in paragraph 6.5.2.4, the expected transmission loss variability over a knife-edge diffraction link can also be associated with the variability of the effective earth radius a as a function of changes in the average refractivity gradient over the path. This is particularly applicable when evaluating the effects of subrefractive conditions where, with increasingly positive refractivity gradients, a diffracting, obstacle intrudes more and more into the free-space propagation path. Applicable cumulative time distributions of initial refractivity gradients above the earth's surface are given in [39] and [100] in terms of AN//lb as well as of the effective earth radius factor k. Samples of such distributions from [100] are shown in figure 6.5-11 together with pertinent climate data. Note that these curves must be extrapolated for extreme percentage values although there rarely are sufficiently complete data to provide a good basis for extrapolation.

6.5.7.4 In order to apply gradient distributions such as shown in figure 6.5-11 to a design problem, diffraction transmission loss calculations are performed using an appropriate range of effective earth radius factor values, and then associating each transmission loss value with the percentage of time corresponding to the effective earth radius factor used. This method should be used with caution since the data in the references cited above represent observations at discrete locations and for very short times only (i.e., once or twice daily). They are not necessarily



Gibraltar (British Colony)

36-09 *N*, 05-21 W. 3 meters MSL

Data: Radiosonde. 0000 and 12002 (0000 and 1200 LST)
1/68 - 12/70

Note : Calculated refractivity gradient between surface and next higher level. See text.

Analyzed by: Davis and Wagner, Environmental Technical Applications Center, U.S. Air Force, Washington, D.C.

Temperature (°F): January 60/50; July 83/68

Mean Dewpoint (°F): January 48; July 63

Precipitation (inches): Annual 32.1; January 6.06; July 0.04

Located on a 2.25 sq. mile peninsula *on the* southern tip of Spain. Maritime climate with hot and nearly rainless summers and warm, rainy winters.

Figure 6.5-11 Examples of Refractivity Gradient Distributions.

representative of conditions occuring over a path of given length, and all hours of the day. Boithias and Battesti [104] give applicable estimates of the minimum effective value of the effective earth radius factor k as a function of path length in a continental temperate climate.

6.5.8 Worksheets for Diffraction Calculations And An Example.

6.5.8.1 Worksheets 6.5-1, 6.5-2, and 6.5-3 (on two pages) with step-by-step procedures for knife-edge diffraction calculations are included in this section. The various steps in the calculations are referred to appropriate formulas, graphs, and paragraphs in the text of section 6.5, or to earlier sections or paragraphs in this handbook where appropriate.

6.5.8.2 As an illustrative example, filled-in worksheets are also provided for an assumed 55 km link operating on 6 GHz using vertical polarization. Figure 6.5-12 shows the assumed path profile with the direct-ray path indicated for an effective earth radius a = 8820 km corresponding to an average value of surface refractivity $\overline{N}_s$ = 320 N-units. The path is assumed to go from terminal 1 on an island off-shore via an on-shore obstacle to terminal 2 on a hilltop farther inland so that one portion of the path is over sea water. Inspection of the path profile also suggests that sufficient clearance between the ray path and the terrain is available for the overland portion of the path, but not for the sea portion. Thus, the $G(h_1)$ function must be calculated while the $G(h_2)$ function can be neglected. This is also confirmed by use of the criteria given in paragraph 6.5.5.2. It is also assumed that the obstacle is about 50 m (0.05 km) wide at the top. In an actual case, this could be determined from detailed maps or from a path survey.

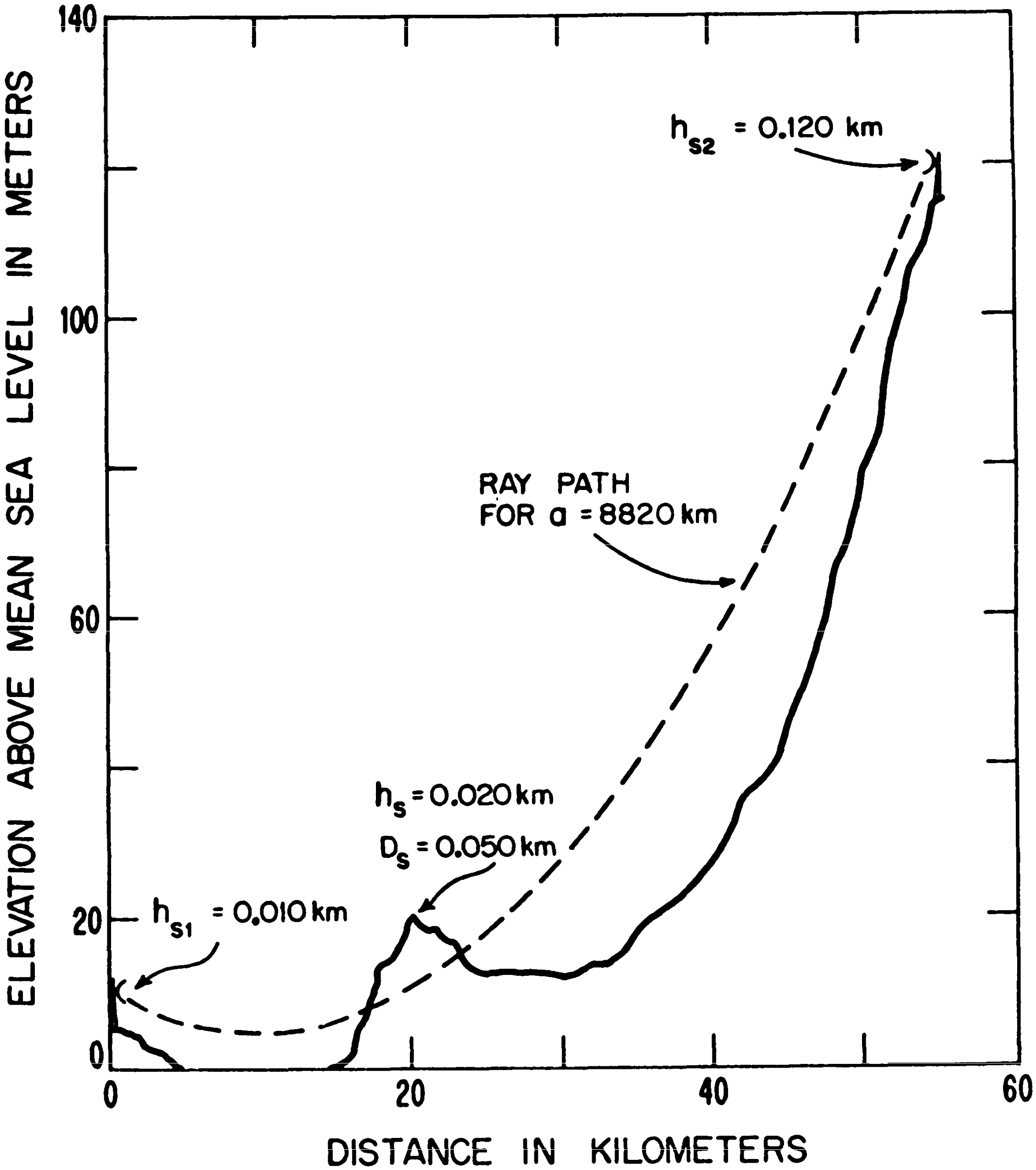


Figure 6.5-12 Flat-Earth Profile for Knife-Edge Diffraction Example Path.

1.1	Estimate $\overline{N}_o$ from map	______N-units		fig. 6.5-1
1.2	Tabulate horizon and antenna site elevations	h_s = ______km e_{s1} = ______km e_{s2} = ______km	from terrain profile and site information	worksheet 4.4-4 step 7 &8
1.3	Is e_{s1} more than 0.15 km lower than h_s?		If yes, use e_{s1} in step 1.5 instead of h_s	par. 6.5.2.2
1.4	Is e_{s2} more than 0.15 km lower than h_s?		If yes, use e_{s2} in step 1.5 instead of h_s	par. 6.5.2.2
1.5	Determine $\overline{N}_{s1,2}$ using h_s or appropriate substitute values	$\overline{N}_{s1}$ = ______N-units $\overline{N}_{s2}$ = ______N-units	$\overline{N}_s = \overline{N}_o \exp(-0.1057\, h_s)$	par. 6.5.2.2
1.6	Take average of $\overline{N}_{s1}$ and and $\overline{N}_{s2}$ when required	$\overline{N}_s$ = ______N-units	$\overline{N}_s = (\overline{N}_{s1} + \overline{N}_{s2})/2$	para. 6.5.2.2
1.7	Determine effective earth radius, a	a = ______km		fig. 6.5-2
1.8	Tabulate total path distance and distances to horizon	d = ______km d_{L1} = ______km d_{L2} = ______km	} from terrain profiles	worksheet 4.4-5, step 39
1.9	Determine median atmospheric absorption	A_a = ______dB	Use carrier frequency ____GHz from worksheet 4.4-4, step (23)	par. 4.2.22.2 or fig. 4.2-8
1.10	Tabulate antenna elevations above mean sea level	h_{s1} = ______km h_{s2} = ______km	$h_{s1} = e_{s1} + h_{g1}$ $h_{s2} = e_{s2} + h_{g2}$	worksheet 4.4-4 step 7, 8, 13& 14
1.11	Calculate horizon elevation angles	θ_{e1} = ______rad θ_{e2} = ______rad	equations 6.5-4a and 6.5-4b	par. 6.5.3.1
1.12	Calculate angles α_o and β_o	α_o = ______rad β_o = ______rad	equations 6.5-5a and 6.5-5b	par. 6.5.3.1
1.13	Calculate diffraction angle θ	θ = ______rad	$\theta = \alpha_o + \beta_o$	par. 6.5.3.1

Worksheet 6.5-1. Atmospheric and Terrain Perameters for Knife-edge Diffraction Calculations

2.1	Calculate diffraction parameter, v	v=______	$v=2.5830\sqrt{f_{L1}d_{L2}}$	par. 6.5.4.2 eq. 6.5-7
2.2	Can rounding of obstacle be estimated	If yes, continue If no, an appears of rounding, go to step 2.12 If no, and (D_S<30 m) go to step 2.7	path profile or other available terrain information	par. 6.5.6
2.3	Estimate D_S	D_S=___km	terrain information	par. 6.5.3.1
2.4	Calculate r	r=___km	$r=D_S/\theta$	eq. 6.5-15
2.5	Check isolation of knife-edge	$kh[2/(kr)]^{1/3}$=___	procedures in text	par. 6.5.6.2
2.6	Is rounded knife-edge isolated	If yes, continue. If no, use procedures in MIL-HDBK-417	If knife-edge is not isolated, diffraction calculation methods are not applicable.	par. 6.5.6.2
2.7	Determine A(v,o)	A(v,o)=___dB	fig. 6.5-3, 6.5-8, 6.5-9, or eq.(6.5-8) for $v\geq3$	par. 6.5.4.3

(If knife-edge is clearly ideal, go to step 3.1)

2.8	Calculate $v\rho$	$v\rho$=___	$v\rho= 1.746\theta(fr)^{1/3}$	eq. 6.5-17 par. 6.5.6.3
2.9	Calculate ρ	ρ=___	$\rho=v\rho/v$	par. 6.5.6.3
2.10	Determine $A(o,\rho)$	$A(o,\rho)$=___dB	fig. 6.5-10	par. 6.5.6.3
	and $U(v,\rho)$	$U(v,\rho)$___dB		
2.11	Calculate $A(v,\rho)$	$A(v,\rho)$=___dB	$A(v,o)+A(o,\rho)$ $+U(v,\rho)$	par. 6.5.6.3 eq. 6.5-18
2.12	If rounding could not be estimated, A(v,o) from graph	A(v,o)=___dB	fig. 6.5-8	par. 6.5.6.1

Worksheet 6.5-2. Diffraction Attenuation Calculations

3.1	Determine carrier wave length, λ	λ = ______km	$\lambda = 0.29979/f_{MHz}$	par. 6.5.5.1 eq. 6.5-9
3.2	Calculate $\sqrt{\lambda d}_{L1}$ and $\sqrt{\lambda d}_{L2}$	$\sqrt{\lambda d}_{L1}$ = ______km $\sqrt{\lambda d}_{L2}$ = ______km	λ, d_{L1}, d_{L2} in km	steps 1.8 &3.1 par. 6.5.5.2
3.3	Calculate $\lvert h_s - h_{s1}\rvert$ and $\lvert h_s - h_{s2}\rvert$	$\lvert h_s - h_{s1}\rvert$ = ______km $\lvert h_s - h_{s2}\rvert$ = ______km	h, h_{s1}, h_{s2} in km	steps 1.2& 1.10 par. 6.5.5.2
3.4	If both $\sqrt{\lambda d}_{L1} \le \lvert h_s - h_{s1}\rvert$ and $\sqrt{\lambda d}_{L2} \le \lvert h_s - h_{s2}\rvert$, $G(\bar{h}_1) = G(\bar{h}_2) = 0$; go to step 3.18 (see paragraph 6.5.5.2 for additional discussion).			par. 6.5.5.2
3.5	If either one or both $\sqrt{\lambda d}_{L1} > \lvert h_s - h_{s1}\rvert$ and $\sqrt{\lambda d}_{L2} > \lvert h_s - h_{s2}\rvert$, continue (subsequent calculations to determine either $G(\bar{h}_1)$ or $G(\bar{h}_2)$, or both as required)			par. 6.5.5.2
3.6	Estimate effective antenna heights h_{e1} and h_{e2} as required	h_{e1} = ______km h_{e2} = ______km	from terrain profiles; sec. 6.5.3.1, item (k)	par. 6.5.3.1
3.7	Calculate a_1 and a_2	a_1 = ______km a_2 = ______km	$a_1 = d_{L1}^2/2h_{e1}$ $a_2 = d_{L2}^2/2h_{e2}$	par. 6.5.5.3 eq. 6.5-10a & 6.5-1ob
3.8	Is path over sea water and polarization vertical?	If no, continue If yes, go to step 3.11		par. 6.5.5.3
3.9	Calculate $\bar{h}_1$ and $\bar{h}_2$	$\bar{h}_1$ = ______ $\bar{h}_2$ = ______	eq. 6.5-11a eq. 6.5-11b	par. 6.5.5.3
3.10	Go to step 3.17			
3.11	Determine K_o	K_o = ______	Use curve for sea water and vertical polarization	fig. 6.5-5 par. 6.5.5.4
3.12	Determine b	b = ______°	Use curve for sea water and vertical polarization	fig. 6.5-6; par. 6.5.5.4
3.13	Calculate C_{o1} and C_{o2}	C_{o1} = ______ C_{o2} = ______	$C_{01} = (8500/a_1)^{1/3}$ $C_{02} = (8500/a_2)^{1/3}$	step 3.8; eq. 6.5-12a & 6.5-12b
3.14	Calculate K_1 and K_2	K_1 = ______ K_2 = ______	$K_1 = C_{01}K_0$ $K_2 = C_{02}K_0$	steps 3.8 &3.10 eq. 6.5-13a & 6.5-13b

Worksheet 6.5-3. Effects of Ground Reflections and Diffraction Loss

3.15	Determine $B(K_1,b)$ and $B(K_2,b)$	$B(K_1,b)$ = ______ $B(K_2,b)$ = ______	fig. 6.5-7	steps 3.11 & 3.12 par. 6.5.5.5
3.16	Calculate $\bar{h}_1$ and $\bar{h}_2$	$\bar{h}_1$ = ______ $\bar{h}_2$ = ______	eq. 6.5-14a eq. 6.5-14b	steps 3.7 &3.8 3.14 par. 6.5.5.5
3.17	Determine $G(\bar{h}_1)$ and $G(\bar{h}_2)$	$G(\bar{h}_1)$ = ______dB $G(\bar{h}_2)$ = ______dB	as a function of K; use curve marked K ≤0.001 except for vertical polarization over sea water	fig. 6.5-4; par. 6.5.5.3 & 6.5.5.5.5
3.18	Calculate total diffraction attenuation A_k	A_k = ______dB	use appropriate terms in eq. 6.5-6 as previously calculated	steps 2.7, 2.12 & 3.16; par. 6.5.4.2
3.19	Determine basic transmission loss L_b	L_b = ______dB	$L_b = L_{bf} + A_k + A_a$	step 3.17 & steps (40) & (41) from work- sheet 4.4-5

NOTE: The calculations in these worksheets may be performed for various values of the effective earth radius a in order to obtain a time distribution of L_b as discussed in paragraph 6.5.7.3.

Worksheet 6.5-3 (continued)

1.1	Estimate $\bar{N}_o$ from map	320 N-units		fig. 6.5-1
1.2	Tabulate horizon and antenna site elevations	h_s = 0.02 km e_{s1} = 0.005 km e_{s2} = 0.115 km	from terrain profile and site information	worksheet 4.4.4 steps 7 & 8
1.3	Is e_{s1} more than 0.15 km lower than h_s?	no	If yes, use e_{s1} in step 1.5 instead of h_s	par. 6.5.2.2
1.4	Is e_{s2} more than 0.15 km lower than h_s?	no	If yes, use e_{s2} in step 1.5 instead of h_s	par. 6.5.2.2
1.5	Determine $\bar{N}_{s1,2}$ using h_s or appropriate substitute values	$\bar{N}_{s1}$ = – N-units $\bar{N}_{s2}$ = – N-units	$\bar{N}_s = \bar{N}_o \exp(-0.1057\, h_s)$	par. 6.5.2.2
1.6	Take average of $\bar{N}_{s1}$ and and $\bar{N}_{s2}$ when required	$\bar{N}_s$ = 320 N-units	$\bar{N}_s = (\bar{N}_{s1} + \bar{N}_{s2})/2$	par. 6.5.2.2
1.7	Determine effective earth radius, a	a = 8820 km		fig. 6.5-2
1.8	Tabulate total path distance and distances to horizon	d = 55.0 km d_{L1} = 20.0 km d_{L2} = 35.0 km	from terrain profiles	worksheet 4.4-5, step 39
1.9	Determine median atmospheric absorption	A_a = 0.6 dB	Use carrier frequency 6.0 GHz from worksheet 4.4-4, step (23)	par. 4.2.22.2 or fig. 4.2-8
1.10	Tabulate antenna elevations above mean sea level	h_{s1} = 0.01 km h_{s2} = 0.12 km	$h_{s1} = e_{s1} + h_{g1}$ $h_{s2} = e_{s2} + h_{g2}$	worksheet 4.4-4, steps 7, 8, 13, & 14
1.11	Calculate horizon elevation angles	θ_{e1} = −0.001083 rad θ_{e2} = −0.004841 rad	equations 6.5-4a and 6.5-4b	par. 6.5.3.1
1.12	Calculate angles α_o and β_o	α_o = 0.000035 rad β_o = 0.000277 rad	equations 6.5-5a and 6.5-5b	par. 6.5.3.1
1.13	Calculate diffraction angle θ	θ = 0.000312 rad	$\theta = \alpha_o + \beta_o$	par. 6.5.3.1

Worksheet 6.5-1. Atmospheric and Terrain Parameters for Knife-edge Diffraction Calculations

2.1	Calculate diffraction parameter, v	v = 0.221	$v = 2.583\theta\sqrt{fd_{L1}\, d_{L2}/d}$	par. 6.5.4.2 eq. 6.5-7
2.2	Can rounding of the obstacle be estimated?	If yes, continue. If no, and there appears to be appreciable rounding, go to step 2.12. If no, and the knife-edge is clearly ideal (D_s <30m) go to step 2.7	from path profile or other available terrain information	sec. 6.5.6
2.3	Estimate D_s	D_s = 0.05 km	from path profile or other available terrain information	par. 6.5.3.1
2.4	Calculate r	r = 160.3 km	$r = D_s/\theta$	eq. 6.5-15
2.5	Check isolation of knife-edge	$kh[2/(kr)]^{1/3}$ = 699	use procedures in text	par. 6.5.6.2
2.6	Is rounded knife-edge isolated?	If yes, continue. If no, use procedures in MIL-HDBK-417	If the rounded knife-edge is not isolated, knife-edge diffraction calculation methods are not applicable.	par. 6.5.6.2
2.7	Determine A(v,o)	A(v,o) = 8.0 dB	fig. 6.5-3, 6.5-8, 6.5-9; or eq. (6.5-8) for v ≥3	par. 6.5.4.3
	(If knife-edge is clearly ideal, go to step 3.1).			
2.8	Calculate vρ	vρ = 0.0536	$v\rho = 1.746\,\theta\,(fr)^{1/3}$	eq. 6.5-17 par. 6.5.6.3
2.9	Calculate ρ	ρ = 0.242	ρ = vρ/v	par. 6.5.63
2.10	Determine A(0,ρ) and U(vρ)	A(0,ρ) = 7.5 dB U(vρ) = -5.9 dB	fig. 6.5-10	par. 6.5.6.3
2.11	Calculate A(v,0)	A(v,ρ) = 9.6 dB	A(v,ρ) = A(v,0) + A(0,ρ) + U(vρ)	par. 6.5.6.3
2.12	If rounding could not be estimated, determine A(v,o) from graph	A(v,o) = ~ dB	fig. 6.5-8	par. 6.5.6.1

Worksheet 6.5-2. Diffraction Attenuation Calculations

3.1	Determine carrier wave length, λ	λ = 5×10^{-5} km	$\lambda = 0.29979/f_{MHz}$	par. 6.5.5.1 eq. 6.5-9
3.2	Calculate $\sqrt{\lambda d}_{L1}$ and $\sqrt{\lambda d}_{L2}$	$\sqrt{\lambda d}_{L1}$ = 0.032 km $\sqrt{\lambda}d_{L2}$ = 0.042 km	λ, d_{L1}, d_{L2} in km	steps 1.8 & 3.1 par. 6.5.5.2
3.3	Calculate $\|h_s - h_{s1}\|$ and $\|h_s - h_{s2}\|$	$\|h_s - h_{s1}\|$ = 0.01 km $\|h_s - h_{s2}\|$ = 0.10 km	h, h_{s1}, h_{s2} in km	steps 1.2 & 1.10 par. 6.5.5.2

3.4 If both $\sqrt{\lambda d}_{L1} \le |h_s - h_{s1}|$ and $\sqrt{\lambda d}_{L2} \le |h_s - h_{s2}|$, $G(\bar{h}_1) = G(\bar{h}_2) = 0$; go to step 3.18 (see paragraph 6.5.5.2 for additional discussion). — par. 6.5.5.2

3.5 If either one or both $\sqrt{\lambda d}_{L1} > |h_s - h_{s1}|$ and $\sqrt{\lambda d}_{L2} > |h_s - h_{s2}|$, continue (subsequent calculations to determine either $G(\bar{h}_1)$ or $G(\bar{h}_2)$, or both as required) — par. 6.5.5.2

3.6	Estimate effective antenna heights h_{e1} and h_{e2} as required	h_{e1} = 0.01 km h_{e2} = ~ km	from terrain profiles; item (k)	par. 6.5.3.1
3.7	Calculate a_1 and a_2	a_1 = 40,000 km a_2 = ~ km	$a_1 = d_{L1}^2/2h_{e1}$ $a_2 = d_{L2}^2/2h_{e2}$	par. 6.5.5.3 eq. 6.5-10a & b
3.8	Is path over sea water and polarization vertical?	If no, continue If yes, go to step 3.11		par. 6.5.5.3
3.9	Calculate $\bar{h}_1$ and $\bar{h}_2$	$\bar{h}_1$ = ~ $\bar{h}_2$ = ~	eq. 6.5-11a eq. 6.5-11b	par. 6.5.5.3
3.10	Go to step 3.17			
3.11	Determine K_o	K_o = 0.0083	Use curve for sea water and vertical polarization	fig. 6.5-5 par. 6.5.5.4
3.12	Determine b	b = 80°	Use curve for sea water and vertical polarization	fig. 6.5-6; par. 6.5.5.4
3.13	Calculate C_{o1} and C_{o2}	C_{o1} = 0.596 C_{o2} = ~	$C_{01} = (8500/a_1)^{1/3}$ $C_{02} = (8500/a_2)^{1/3}$	step 3.8; eq. 6.5-12a & b
3.14	Calculate K_1 and K_2	K_1 = 0.00495 K_2 = ~	$K_1 = C_{01}K_0$ $K_2 = C_{02}K_0$	steps 3.8 & 3.10 eq. 6.5-13a & b

Worksheet 6.5-3. Effects of Ground Reflections and Diffraction Loss

3.15	Determine $B(K_1,b)$ and $B(K_2,b)$	$B(K_1,b)$ = 1.603 $B(K_2,b)$ = ~	fig. 6.5-7	steps 3.11 & 3.12 par. 6.5.5.5
3.16	Calculate $\bar{h}_1$ and $\bar{h}_2$	$\bar{h}_1$ = 0.0335 $\bar{h}_2$ = ~	eq. 6.5-14a eq. 6.5-14b	steps 3.7, 3.8, 3.14; par. 6.5.5.5
3.17	Determine $G(\bar{h}_1)$ and $G(\bar{h}_2)$	$G(\bar{h}_1)$ = −22.8 dB $G(\bar{h}_2)$ = 0 dB	as a function of K; use curve marked K ≤0.001 except for vertical polarization over sea water	fig. 6.5-4; par.6.5.5.3 & 6.5.5.5
3.18	Calculate total diffraction attenuation A_k	A_k = 32.4 dB	use appropriate terms in eq. 6.5-6 as previously calculated	steps 2.7, 2.12 & 3.16; par.6.5.4.2
3.19	Determine basic transmission loss L_b	L_b = 175.8 dB	$L_b = L_{bf} + A_k + A_a$	step 3.17 & step (40) & (41) from worksheet 4.4-5

NOTE: The calculations in these worksheets may be performed for various values of the effective earth radius a in order to obtain a time distribution of L_b as discussed in paragraph 6.5.7.3.

Worksheet 6.5-3 (continued)

Section 6.6 ADDITIONAL BLANK WORKSHEETS

6.6.1 This section includes an additional set of blank worksheets for convenience. They correspond to those in the text as follows:

Worksheet	Page Number for Blank	Page Number for Partially or Completely Filled-in (for Example)
4.1-1	4-5	-
4.3-1	4-80 and 4-81	-
4.3-2	-	4-85
4.4-1	-	4-117
4.4.2	-	4-118
4.4-3	-	4-119
4.4-4	4-120	4-312
4.4-5	4-121	4-313
4.5-la	4-234	-
4.5-lb	4-235	-
4.5-2	4-236	-
4.5-3	-	4-260
4.5-4	4-266	4-314
4.5-5	4-267	4-315
4.5-6	4-268	4-316
4.5-7	4-269	4-317
4.5-8	4-270 and 4-271	4-318 and 4-319
4.5-9	4-272	-
4.5-10	4-273	4-320
4.5-11	4-274	4-321
6.5-1	6-67	6-71
6.5-2	6-68	6-72
6.5-3	6-69 and 6-70	6-73 and 6-74

Current and future channel requirements for traffic

from site______________ to site______________

Type of Channel	Number of Channels	Baseband per Channel	Quality	Equivalent voice channels per information channel	Number of equivalent voice channels	Baseband Spectrum
Voice (Telephone)						
Voice (Facsimile)						
Voice (Low Speed Data)						
Voice (Medium Speed Data)						
Digital Data (High Speed)						
Video						

Totals ______________

Link channel requirements rounded to the next higher nominal value[1] ________

Transmitter RF bandwidth[2] ________

(Future Expansion)

Voice (Telephone)						
Voice (Facsimile)						
Voice (low Speed Data)						
Voice (Medium Speed Data)						
Digital Data {High Speed)						
Video						

[1] Nominal values are 24, 60, 120, 300, 600, 960, and 1800.

[2] Estimate using figure 4.1-1.

Worksheet 4. 1-1 Format for Recording Channel Requirements for FDM-FM Systems.

Site Name and Number____________________

Latitude__________ Longitude__________ (Degrees, Min, See)

Map reference (most detailed topographic)__________

Nearest town (postoffice)__________

Access route: (all Year?)

Property owner; local contact:

Site sketch_____ Site photograph_____ General description________

Reference baseline________ By Polaris_____ Other________

Antenna No. ________ True bearing________

Ground elev. MSL________ Takeoff angle (beam centerline_____

Takeoff angles to 45° right and left of centerline________
(Significant changes in horizon)

Critical Points: (include horizon)

Distance______ Map elev. ______ Survey elev. ______

Tree height______ Required clearance______

Description:

Horizon sketch______ Horizon photograph______

Power availability:

a. Nearest transmission line______ b. Voltage______

c. Frequency______ d. Phase_____ e. Operating utility______

Drinking water source______ Estimated depth to groundwater_____

Sewage disposal______ Type and depth of soil on and near site______

Nearest airport______ railroad______ highway______

navigable river______

Worksheet 4. 3-1 Checklist for Site Survey (page 1 of 2)

Local communications facilities: telephone_____ telegraph_____ radio_____

Nearby radio transmitters________ relay stations________

Other interference sources_______________

Local transportation facilities: airlines________ railroads________

truck________ bus________

Warehouse and storage facilities________

Local suppliers (hardware, lumbers concrete, etc.)________

Local contractors________

Fuel sources (oil, gas, propane)________

Local housing accommodations: temporary_______ permanent_______

Local military or civil contact_________

Meteorological data from local sources: (averages for each month)

Maximum/ minimum temperature (daily) ______

Precipitation ______ (Also extreme 1- and 24-hour)

Snow depth ______ (Also maximum for period of record)

Prevailing wind direction and speed_ .

Extreme wind gust and direction________

Dewpoint or relative humidity (mean diurnal change) ________.

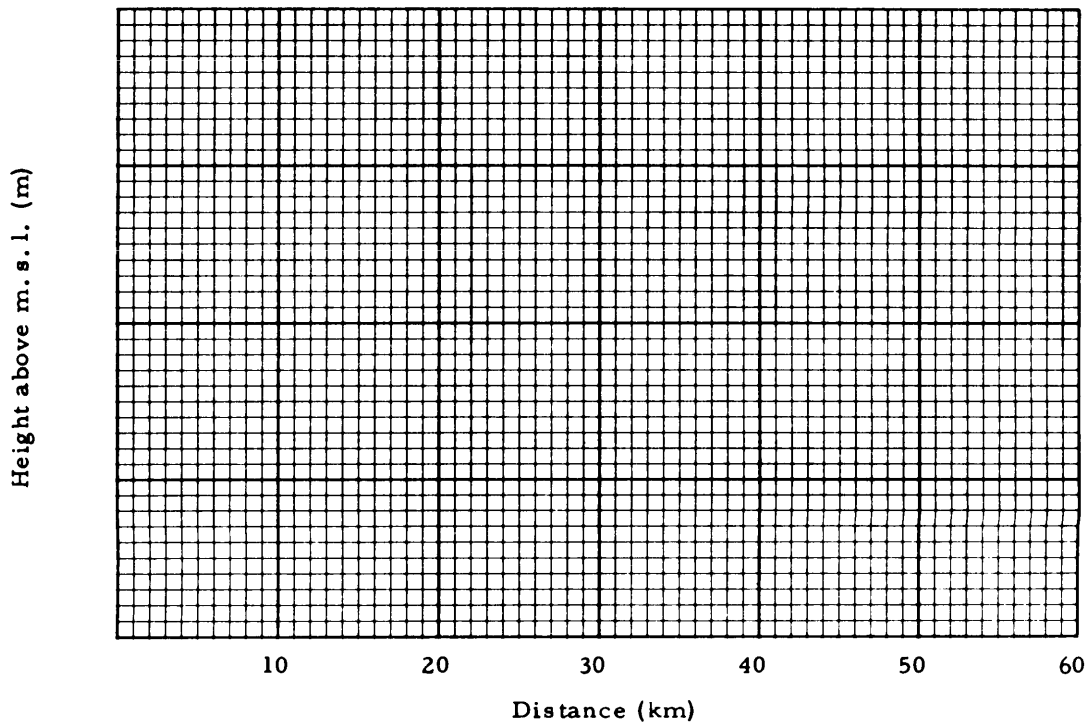
Worksheet 4. 3-1 Checklist for Site Survey (page 2 of 2)

DATE:		OBSERVER:	
SITE NAME and NUMBER:			
LOCATION:	Section	Town	Range
	County	State	Country
REFERENCE MAPS:			
DESCRIPTION:			
ACCESS ROUTE:			
SITE LOCATION SKETCH (not necessarily to scale)			

Worksheet 4.3-2 Site Information Worksheet Blank

Site Identification

From ____________ , ____________ to ____________ , ____________
(Name) (Abbrev.) (Name) (Abbrev.)



Notes:

Worksheet 4.4-1 Link Design Profile

Calculate h, the displacement of the curved earth radio path from the flat earth path (section 4.2. 15).

$$h = \frac{d_1 d_2}{12.75k}$$

where h is in m and d_1 and d_2 in km. Calculate the distance from the center line of the radio beam which will provide 0. 6 of first Fresnel zone clearance, 0.6 R_1 (section 4.2.17).

$$0.6\ R_1 = (0.6)\ (17.3) \sqrt{\frac{1}{f_{GHz}} \quad \frac{d_1 d_2}{d_1 + d_2}}$$

For k = ______________ and f = ________________ GHz,

d_1 (km)	d_2 (km)	$d_1 d_2$	h (m)	$\sqrt{d_1 d_2}$	$0.6R_1$ (m)

Worksheet 4.4-2 Link Design Clearance Calculations

A. Distance on Profile ____________ km.

Ground Elevation ____________ m above m.s.l.

Tree or Obstacle Height ____________ m above ground.

Total Obstruction Height ____________ m above m.s.l.

For an assumed upper antenna height of ______________ m, clearance of

________ m is realized for "k" = ____________ This provides
(worst case)"

________ of ______ Fresnel Zone clearance for this "k" value.
(fraction) (order)

B. Distance on Profile ____________ km.

Ground Elevation ____________ m above m.s.l.

Tree or Obstacle Height ____________ m above ground.

Total Obstruction Height ____________ m above m.s.l.

For an assumed upper antenna height of _______ m, clearance of

________ m is realized for "k" = ____________ This provides
(worst case)"

________ of ______ Fresnel Zone clearance for this "k" value.
(fraction) (order)

C. Distance on Profile ____________ km.

Ground Elevation ____________ m above m.s.l

Tree or Obstacle Height ____________ m above ground.

Total Obstruction Height ____________ m above m.s.l

For an assumed upper antenna height of ________ m, clearance of

________ m is realized for "k" = ____________ This provides
(worst case)"

________ of ______ Fresnel Zone clearance for this "k" value.
(fraction) (order)

Worksheet 4.4-3 Link Design Clearance Check

Site Identification

(1)__________, __________ (Name) (Abbreviation)	(2)__________, __________ (Name) (Abbreviation)

Site Location and Physical Parameters

(3) Latitude____ ____ ____ ____	(4) Latitude____ ____ ____ ____	sec. 4.4.3
(5) Longitude____ ____ ____ ____	(6) Longitude____ ____ ____ ____	sec. 4.4.3
(7) Altitude above mean sea level_______m.	(8) Altitude above mean sea level_______m.	sec. 4.4.3
(9) UTM Coord.______________	(10) UTM Coord. ______________	sec. 4.2.14.
(11) Azimuth to (2), ____ ____ ____ True	(12) Azimuth to (1), ____ ____ ____ True	sec. 4.2.16
(13) Proposed upper antenna height above (7),________m.	(14) Proposed upper antenna height above (8),________m.	Worksheet 4.4-1
(15) Proposed vertical diversity antenna separation from (13), _______m.	(16) Proposed vertical diversity antenna separation from (14), _______m.	sec. 4.4.24
(17) Proposed antenna type, ____________________	(18) Proposed antenna type, ____________________	
(19) Size_____ft, __________m	(20) Size_____ft, __________m	fig. 4.4-33
(21) Expected antenna gain _____dB above isotropic	(22) Expected antenna gain _____dB above isotropic	fig. 4.4-30
(23) Design center carrier frequency _______GHz.	(24) Receiver noise threshold $-174 + 10 \log B_{IF} + F$ _____dBm.	par. 4.4.2.2

Worksheet 4.4-4. Link Design Summary, Part 1

(25) Required waveguide length, ______m.	(26) Required waveguide length, ______m.	Worksheet 4.4-1 (for tower heights)
(27) Proposed waveguide type __________	(28) Proposed waveguide type __________	sec. 4.4.40
(29) Waveguide loss per standard length ____dB per ______m	(30) Waveguide loss per standard length ____dB per________m	fig. 4.4-43
(31) Waveguide loss $A_{t\ell}$ _____dB (including connectors)	(32) Waveguide loss $A_{t\ell}$ _____db (including connectors)	fig. 4.4-43
(33) Circulator and/or Diplexer Losses A_c Transmit________dB	(34) Circulator and/or Diplexer Losses A_c Receive________dB	par. 4.4.43.1
(35) Isolator Losses A: Transmit ___________dB	(36) Isolator Losses A: Receive _________dB	

(37) Net fixed losses, (31) + (32) + (33) + (34) + (35) + (36), _______dB.

(38) Proposed transmitter power ____ watts, ______dBm. — sec. 4.4.44

(39) Path length _________ km. — worksheet 4.4-1

(40) Free space basic transmission loss, L_{bf}, _______dB. — fig. 4.2-7 or (4.2-1)

(41) Atmospheric absorption, A_a, ________dB. — fig. 4.2-8 and sec. 4.2.22

(42) Net loss, (37) + (40) + (41),_______dB.

(43) Net gain (21) + (22) + (38) (dBm)________dBm.

(44) Expected median receiver input power, P_r, (43) - (42) ____dBm.

(45) Order of diversity used______________.

(46) Type of diversity combiner used__________.

(47) Rain rate zone ____________. — fig. 4.2-11 or 4.2-13

Worksheet 4.4-5. Link Design Summary, Part 2

Site Name & Antenna Designation	Site & Antenna Abbreviation	Latitude	Longitude	Tower Base Elevation above m.s.l. (m)

Worksheet 4.5-1 a Site Location Summary

Worksheet 4.5-1 b Antenna Information Summary

Antenna Ident. No.	Site	Path	Pointing Azimuth from True North	Height above Ground (m)	Frequency (GHz)	Polarization (V or H)	Type	Diameter (ft)	Antenna Gain (dBi)	Beamwidth (degrees)	Function (Rx or Tx)

No.	Path	Profile No.	Tower Base Elevation above m.s.l. (m)	Tower Height (m)	Distance (km)	Frequency (GHz)	Free Space Basic Transmission Loss (dB)	Feeder Length (m)	Filter & Feeder Loss (dB)	Total Loss (dB)	Antenna Size (feet)	Passive Reflector Size (ft)	Highest Antenna or Reflector Height above Ground (m)	Antenna Gain, dB above Isotropic	Net Path Loss (dB)	Transmit Power (dBm)	Median Received Carrier Level (dBm)	IF Bandwidth (MHz)	Receiver Noise Figure (dB)	KTBF (dBm)	C/N (dB)		

Worksheet 4.5-2 Path Parameter Summary

Link	A	B	C	D	E	F	G	H	
Thermal Noise Equip Intermod Feeder Echo Estimated Total Noise									
Allocated Noise									Total Noise Allocated pW

Worksheet 4.5-3 First Cut FM-FDM System/Hop Noise Allocation

4.1	Number of equivalent voice channels, n	______			sec. 4.1.3
4.2	Voice channel bandwidth, b_c	3100	Hz	(Usable bandwidth)	
4.3	Maximum modulating frequency, f_m	______	kHz		table 4.5-2 (upper baseband limit)
4.4	Baseband bandwidth, B_b	______	kHz	$B_b = f_m - f_\ell$, where f_ℓ is the lowest frequency in baseband	table 4.5-2
4.5	RMS load factor, LF	______	dBm0	-10 + 10 log n	step 4.1; par. 4.5.27.2
4.6	Numerical RMS load factor ℓf	______		antilog(LF/20)	step 4.5
4.7	Peak factor, PF	13.5	dB		par. 4.5.27.2
4.8	Numerical peak factor, pf	4.73		antilog(PF/20)	step 4.7
4.9	RMS per channel deviation, δf	______	kHz		par. 4.5.16.4 & table 4.5-2
4.10	RMS carrier deviation, δF	______	kHz	$\delta F = (\ell f)(\delta f)$	steps 4.6 & 4.9
4.11	Peak carrier deviation, ΔF	______	kHz	$\Delta F = (pf)(\ell f)(\delta f)$	steps 4.6, 4.8, & 4.9
4.12	Receiver IF bandwidth, B_{IF}	______	kHz	$B_{IF} = 2(\Delta F + f_m)$	steps 4.3 & 4.11, also table 4.5-2
4.13	Receiver noise figure, F	______	dB		par. 4.5.16.4 & 4.4.45.13
4.14	Receiver noise threshold	- ______	dBm	$-174 + 10 \log B_{IF}(\text{Hz}) + F$	steps 4.12, 4.13 or par. 4.5.27.2
4.15	FM improvement threshold	- ______	dBm	$-174 + 10 \log B_{IF}(\text{Hz}) + F + 10$	par. 4.5.27.2
4.16	Pre-emphasis improvement, I_p	4	dB		sec. 4.5.26
4.17	Median diversity improvement, I_d	______	dB		par. 4.5.34.1 worksheet 4.4.-5 step (46)
4.18	Radio set NPR	______	dB		par. 4.5.20.3

Worksheet 4.5-4. Basic Parameters for Median Noise Calculations

5.1	Transmission line or wave-guide length, transmitter	______m		worksheet 4.4-4 & sec. 4.5.19
	Type of transmission line or waveguide	______		
5.2	Percent velocity of propagation	______%v		fig. 4.5-18
5.3	Velocity of propagation, v	______m/sec	$v = (3 \times 10^{8})\ (\%v \times 10^{-2})$	par. 4.5.21.4
5.4	Echo delay time,	______sec	$\tau = 2L/v$	par. 4.5.21.4
5.5	Radian delay	______rad	$2\pi f_m \tau$	par. 4.5.21.4
5.6	Parameter A	______	$A = \delta F/f_m$	par. 4.5.21.4
5.7	S/D - r	______dB		fig. 4.5-19 par. 4.5.21.4
5.8	Transmit system			par. 4.5.21.5
	Antenna return loss RL_{ANT}	______dB		from application standards or manufacturer's specifications
	RF interface return loss RL_{RFI}	______dB		
5.9	Echo amplitude, r	______dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$	par. 4.5.21.5 step 5.8 &step (31) worksheet 4.4-5
5.10	Transmit signal-to-distortion ratio, S/D	______dB	$S/D = (S/D - r) + r$	par. 4.5.21.8 steps 5.7 & 5.9
5.11	Transmit signal-to-feeder echo noise, S/N_f	______dB	$S/N_f = S/D + 10 \log \frac{B_b}{b_c} - LF$	par. 4.5.21.8
5.12	Transmit feeder echo noise, $N_{f(trans.)}$	______pW0	$N_f = \text{antilog} \frac{90 - S/N_f}{10}$	par. 4.5.21.8

Worksheet 4.5-5. Transmitter Feeder Echo Noise Calculation

6.1	Transmission line or waveguide length, receiver	_____ m		worksheet 4.4-4 sec. 4.5.19
	Type of line or waveguide	_____		
6.2	Percent velocity of propagation	_____ %v		fig. 4.5-18
6.3	Velocity of propagation, v	_____ m/sec	$v = (3 \times 10^8)(\%v \times 10^{-2})$	par. 4.5.21.4
6.4	Echo delay time, τ	_____ sec	$\tau = 2L/v$	par. 4.5.21.4
6.5	Radian delay	_____ rad	$2\pi f_m \tau$	par. 4.5.21.4
6.6	Parameter A	_____	$A = \delta F/f_m$	par. 4.5.21.4
6.7	S/D - r	_____ dB		fig. 4.5-19 par. 4.5.21.4
6.8	Receive system			par. 4.5.21.5
	Antenna return loss	RL_{ANT} _____ dB		from application standards or manufacturer's specifications
	RF interface return loss	RL_{RFI} _____ dB		
6.9	Echo amplitude, r	_____ dB	$r = RL_{ANT} + RL_{RFI} + 2A_{t\ell}$	par. 4.5.21.5 step 6.8 & step(32) worksheet 4.4-5
6.10	Receive signal-to-distortion ratio, S/D	_____ dB	$S/D = (S/D - r) + r$	par. 4.5.21.8 steps 6.7 & 6.9
6.11	Receive signal-to-feeder echo noise, S/N_f	_____ dB	$S/N_f = S/D + 10 \log \frac{B_b}{b_c} - LF$	par. 4.5.21.8
6.12	Receive feeder echo noise, $N_{f(receive)}$	_____ pW0	$N_f = \text{antilog} \frac{90 - S/N_f}{10}$	par. 4.5.21.8

Worksheet 4.5-6. Receiver Feeder Echo Noise Calculation

7.1	Total feeder echo noise, N_f	______pWO	$N_f = N_{f(trans)} + N_{f(receive)}$	steps 5.12 & 6.12
7.2	Signal/equipment intermodulation, S/N_e	______dB	$S/N_e = NPR + 10 \log \frac{B_b}{b_c} - LF$	steps 4.2, 4.4 4.5, 4.18 & sec. 4.5.20
7.3	Equipment intermodulation noise, N_e	______pWO	$N_e = \text{antilog} \frac{90 - S/N_e}{10}$	
7.4	Calculate $20 \log \frac{\delta f}{f_m}$	______dB		steps 4.3, 4.9 & par. 4.5.27.2
7.5	Calculate $10 \log KTb_c + F$	______dBm	$-139.1 + F$	step 4.13 & par. 4.5.27.2
7.6	Signal-to-thermal noise ratio minus received signal level, $S/N_t - P_r$	______dB	$S/N_t - P_r = -10 \log KTb_c - F + 20 \log (\delta f/f_m)$	steps 7.4 & 7.5 & par. 4.5.27.2
7.7	Draw quieting curve on worksheet 4.5-10			par. 4.5.27.3
7.8	$P_r(0.5) = (P_r - 3\ dB)$	______dBm		par. 4.5.18.1 & worksheet 4.4-5
7.9	Median signal-to-thermal noise ratio, $S/N_t(0.5)$	______dB	$(S/N_t - P_r) + P_r(0.5)$	steps 7.6 & 7.8
7.10	Median thermal noise, $N_t(0.5)$	______pWO	$N_t(0.5) = \text{antilog} \frac{90 - S/N_t(0.5)}{10}$	step 7.9
7.11	Emphasis-improved signal-to-thermal noise ratio, $S/N_{te}(0.5)$	______dB	$S/N_{te}(0.5) = S/N_t(0.5) + I_p$	steps 7.9 &4.16
7.12	Emphasis-improved thermal noise, $N_{te}(0.5)$	______pWO	$N_{te}(0.5) = \text{antilog} \frac{90 - S/N_{te}(0.5)}{10}$	step 7.11
7.13	Total median noise, $N_T(0.5)$	______pWO	$N_T(0.5) = N_{te}(0.5) + N_f + N_e$	steps 7.12, 7.1 & 7.3

<u>Note:</u> Median values are denoted by (0.5).

Worksheet 4.5-7. Calculate Median Total Noise Performance

8.1	Fade margin, M_f	______dB	$P_r(0.5)$-FM Imp. Thresh., or $P_r(0.5)-30 + (S/N_t - P_r)$, whichever is smaller	steps 4.15, 7.8, & 7.9 sec. 4.5.16
8.2	Percent time M_f is exceeded, P_{mf}	______%	$P_{mf} = 6x10^{-5} a \times b \times f \times d^3 \times 10^{-(M_f/10)}$	sec. 4.2.27 & par. 4.5.33.1
8.3	Divide M_f by path length d or 10, whichever is less	______dB/km		par. 4.2.24.2
8.4	Percent time fade margin is exceeded due to rain attenuation, P_{mfr}	______%	Enter value from step 8.3 as ordinate on graph of fig. 4.2-12 for the appropriate rain zone and read % time value of abscissa for carrier frequency, f	worksheet 4.4-4 step (23) worksheet 4.4-5, step (47) fig. 4.2-12 par. 4.5.32.3
8.5	Total percent time fade margin is exceeded, P_{mft}	______%	$P_{mft} = P_{mf} + P_{mfr}$	steps 8.2 & 8.4
8.6	Received signal level at FM threshold, P_{rTH}	______dBm	$P_r(0.5) - M_f$	steps 7.8 & 8.1
8.7	Thermal signal-to-noise ratio at threshold, S/N_{tTH}	______dB	$(S/N_t - P_r) + P_{rTH}$	steps 7.6 & 8.6
8.8	Emphasis-improved, $S/N_{tTH}(E)$	______dB	$S/N_{tTH} + I_p$	step 8.7 & 4.16
8.9	Emphasis-improved thermal noise at threshold, $N_{tTH}(E)$	______pWO	anilog $\frac{90 - S/N_{tTH}(E)}{10}$	step 8.8
8.10	Total path-independent non-linear noise, N_{im}	______pWO	$N_f + N_e$	steps 7.1 & 7.3
8.11	Total emphasis-improved noise at FM threshold, $N_{TTH}(E)$	______pWO	$N_{im} + N_{tTH}(E)$	steps 8.9 & 8.10
8.12	Is total noise $N_{TTH}(E)$ $\leq$1,000,000 pWO and percent time P_{mft} less than 5×10^{-4}?	______ (yes or no)		steps 8.5 & 8.11

Worksheet 4.5-8. Calculate Short-Term Noise Performance

8.13 If "yes", and diversity was not selected previously, link design is completed. If "no", or diversity has already been selected, continue. If "no", and diversity was not selected previously, re-do steps 4.17, 4.18, and 7.2 through 8.12; then continue.

8.14	Plot line for non-diversity fade margin versus % of time on worksheet 4.5-11			par. 4.5.34.1 steps 8.1 & 8.5
8.15	Read diversity improvement at percentage P_{mft} and other desired percentage values for type of combiner used	_____I_d (_____%)		fig. 4.5-21 worksheet 4.4-4 step (46); step 8.5
8.16	Decrease fade margin values at P_{mft} and other desired percentage values by the appropriate I_d values	_____dB	$M_f - I_d$(_____%)	steps 8.14 & 8.15 par. 4.5.34.1
8.17	Plot line for diversity-improved fade margin versus % of time on worksheet 4.5-11			step 8.16 par. 4.5.34.1
8.18	Diversity and emphasis improved thermal signal-to-noise ratio $S/N_t(E,D)$ at P_{mft} percentage of time	_____dB	$S/N_{tTH} + I_p + I_d$(_____%)	steps 8.8 & 8.15
8.19	Diversity and emphasis improved thermal noise $N_t(E,D)$ at P_{mft} percentage of time	_____pWO	antilog $\frac{90 - S/N_t(E,D)}{10}$	step 8.18
8.20	Estimated total percent of outage time after diversity and emphasis improvement	_____%	Read abscissa for diversity-improved fade margin line on worksheet 4.5-11 where it intersects the ordinate value for M_f	steps 8.1 & 8.17
8.21	Total noise $N_T(E,D)$ at P_{mft} percentage of time	_____pWO	$N_t(E,D) + N_{im}$	steps 8.10 & 8.19
8.22	Is total noise ≤1,000,000 pWO	_____(yes or no)	If answers are no, adjust parameters and recalculate noise performance	
8.23	Is total outage time 5×10^{-4}%	_____(yes or no)		
8.24	If total noise cannot be reduced to ≤1,000,000 pWO, estimate percentage of time during which 1,000,000 pWO is exceeded	_____%	Calculate ratio of total noise to 1,000,000 pWO, converted to dB, subtract from M_f, and read on the diversity improved line of worksheet 4.5-11 the percentage value corresponding to this ordinate	step 8.1 worksheet 4.5-11

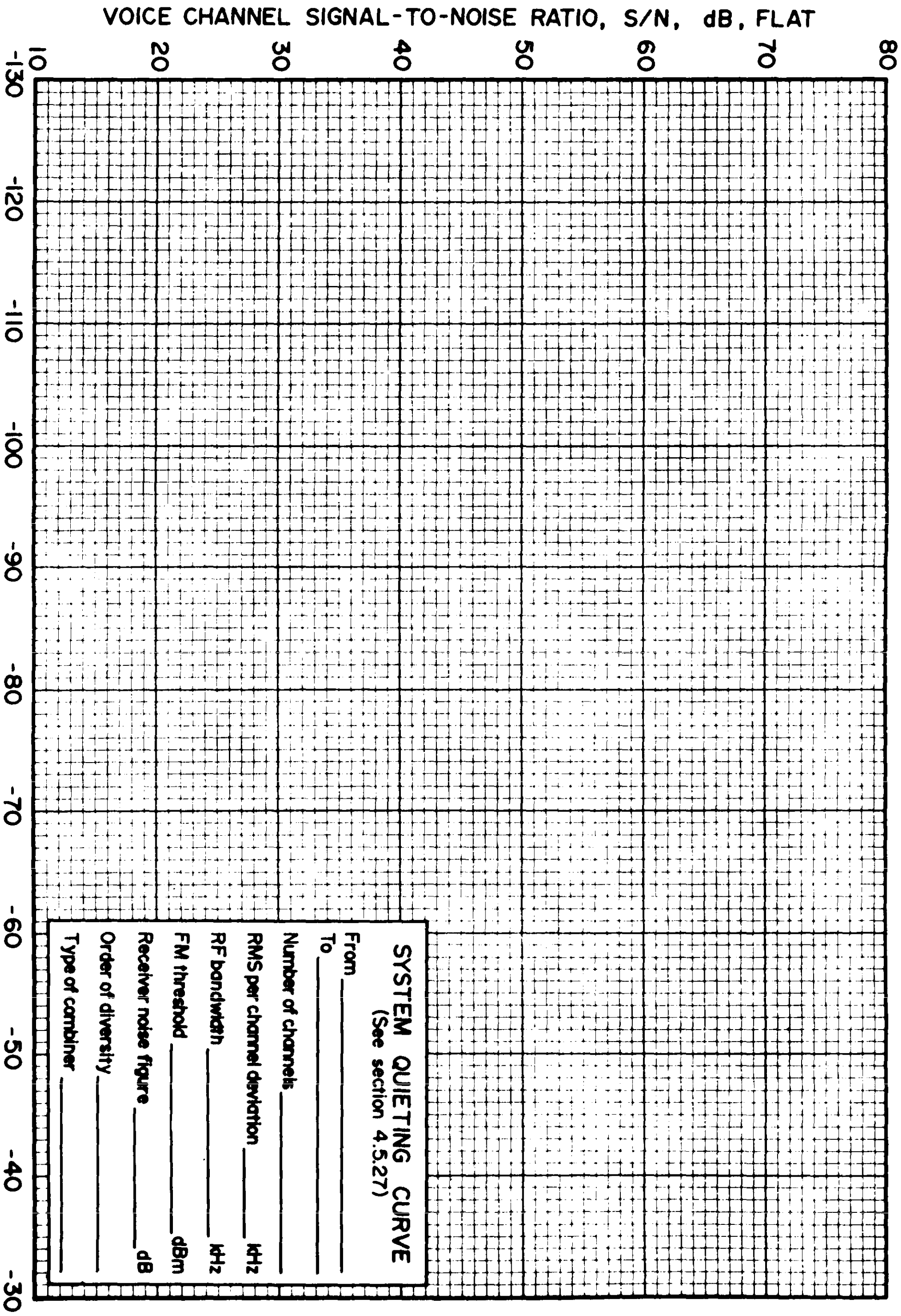
Worksheet 4.5-8. Calculate Short-Term Noise Performance (continued)

No.	Path	Terminal	No. of Channels	Hop Time Availability (Percentile)	C/N Front End (dB)	Highest BB Frequency (MHz)	Fade Margin (dB)	Diversity Improvement (dB)	Top Channel Noise Power, Unweighted (picowatts)					Total Channel S/N, flat, (dB)			Percent of Time Hop Exceeds 10' pW0 (flat)	Noise Allocation
									Thermal	Intermod-ulation	Feeder Echo	Emphasis-Improved Thermal	Total					
TOTALS																		

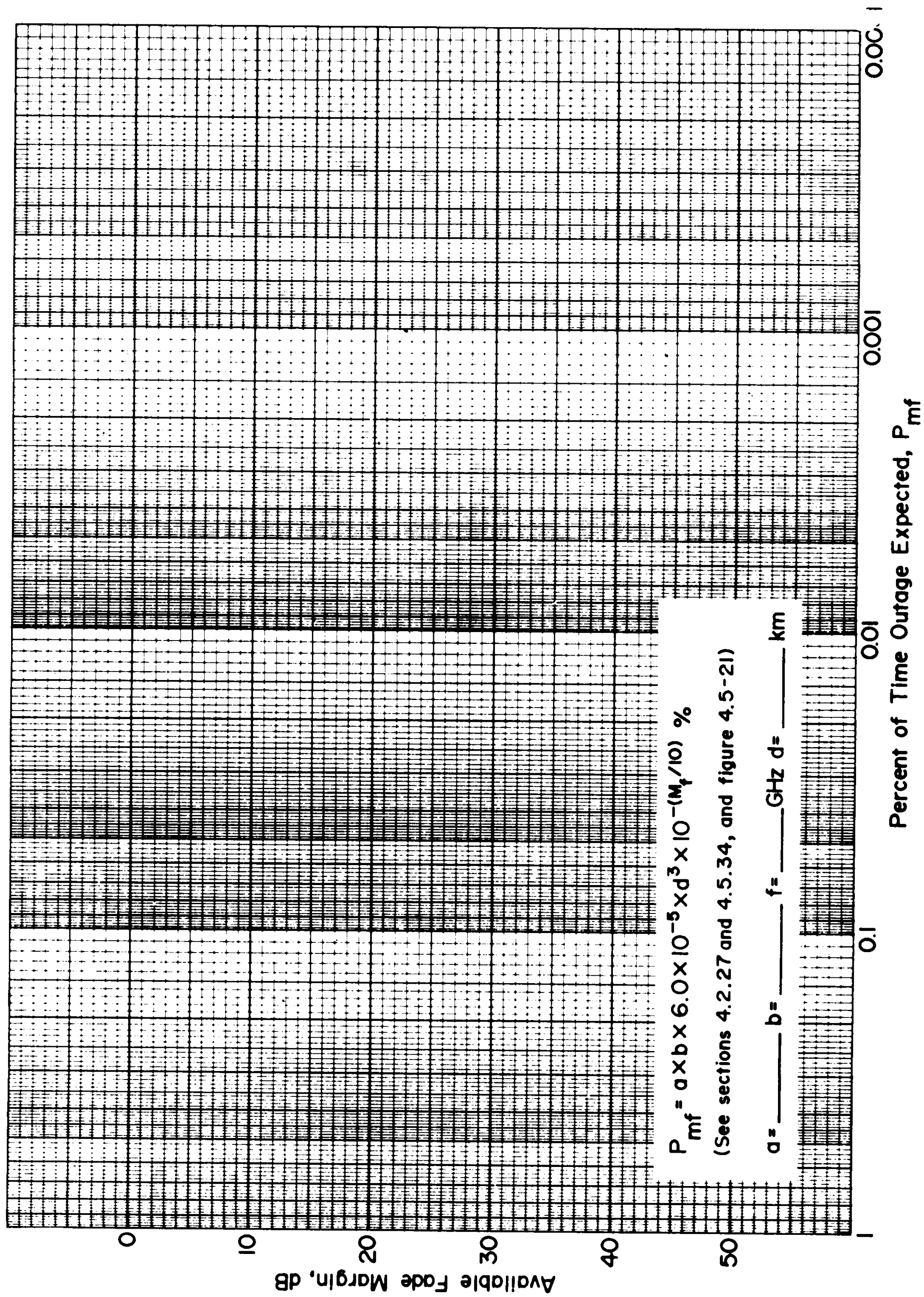
Note: If DCS noise allowance is less than predicted performance, state reasons why it could not be achieved.

Long-term DCS System Noise Allocation______pW0, based on L = ______km
Long-term predicted System Noise Performance______pW0
Estimated System Outage Time______% of year, ______min

Worksheet 4.5-9 FM/FDM System/Hop Noise Allocation



Worksheet 4.5-10. Graph for System Quieting Curve



Worksheet 4.5-11. Non-Diversity and Diversity Improved Fade Margins

1.1	Estimate $\overline{N}_o$ from map	______N-units		fig. 6.5-1
1.2	Tabulate horizon and antenna site elevations	h_s = ______km e_{s1} = ______km e_{s2} = ______km	from terrain profile and site information	worksheet 4.4-4 steps 7 & 8
1.3	Is e_{s1} more than 0.15 km lower than h_s?		If yes, use e_{s1} in step 1.5 instead of h_s	par. 6.5.2.2
1.4	Is e_{s2} more than 0.15 km lower than h_s?		If yes, use e_{s2} in step 1.5 instead of h_s	par. 6.5.2.2
1.5	Determine $\overline{N}_{s1,2}$ using h_s or appropriate substitute values	$\overline{N}_{s1}$ = ______N-units $\overline{N}_{s2}$ = ______N-units	$\overline{N}_s = \overline{N}_o \exp(-0.1057\ h_s)$	par. 6.5.2.2
1.6	Take average of $\overline{N}_{s1}$ and and $\overline{N}_{s2}$ when required	$\overline{N}_s$ = ______N-units	$\overline{N}_s = (\overline{N}_{s1} + \overline{N}_{s2})/2$	par. 6.5.2.2
1.7	Determine effective earth radius, a	a = ______km		fig. 6.5-2
1.8	Tabulate total path distance and distances to horizon	d = ______km d_{L1} = ______km d_{L2} = ______km	from terrain profiles	worksheet 4.4-5 step 39
1.9	Determine median atmospheric absorption	A_a = ______dB	Use carrier frequency ____GHz from worksheet 4.4-4, step (23)	par. 4.2.22.2 or fig. 4.2-8
1.10	Tabulate antenna elevations above mean sea level	h_{s1} = ______km h_{s2} = ______km	$h_{s1} = e_{s1} + h_{g1}$ $h_{s2} = e_{s2} + h_{g2}$	worksheet 4.4-4 steps 7, 8, 13, & 14
1.11	Calculate horizon elevation angles	θ_{e1} = ______rad θ_{e2} = ______rad	equations 6.5-4a and 6.5-4b	par. 6.5.3.1
1.12	Calculate angles α_o and β_o	α_o = ______rad β_o = ______rad	equations 6.5-5a and 6.5-5b	par. 6.5.3.1
1.13	Calculate diffraction angle θ	θ = ______rad	$\theta = \alpha_o + \beta_o$	par. 6.5.3.1

Worksheet 6.5-1. Atmospheric and Terrain Parameters for Knife-edge Diffraction Calculations

2.1	Calculate diffraction parameter, v	v = ______	$v = 2.583\theta\sqrt{fd_{L1}d_{L2}/d}$	par. 6.5.4.2 eq. 6.5-7
2.2	Can rounding of the obstacle be estimated?	If yes, continue. If no, and there appears to be appreciable rounding, go to step 2.12. If no, and the knife-edge is clearly ideal (D_s <30m) go to step 2.7	from path profile or other available terrain information	sec. 6.5.6
2.3	Estimate D_s	D_s = ______km	from path profile or other available terrain information	par. 6.5.3.1
2.4	Calculate r	r = ______km	$r = D_s/\theta$	eq. 6.5-15
2.5	Check isolation of knife-edge	$kh[2/(kr)]^{1/3}$ = ______	use procedures in text	par. 6.5.6.2
2.6	Is rounded knife-edge isolated?	If yes, continue. If no, use procedures in MIL-HDBK-417	If the rounded knife-edge is not isolated, knife-edge diffraction calculation methods are not applicable.	par. 6.5.6.2
2.7	Determine A(v,o)	A(v,o) = ______dB	fig. 6.5-3, 6.5-8, 6.5-9; or eq. (6.5-8) for v ≥3	par. 6.5.4.3
	(If knife-edge is clearly ideal, go to step 3.1).			
2.8	Calculate vρ	vρ = ______	$v\rho = 1.746\theta(fr)^{1/3}$	eq. 6.5-17 par. 6.5.6.3
2.9	Calculate ρ	ρ = ______	ρ = vρ/v	par. 6.5.6.3
2.10	Determine A(0,ρ) and U(vρ)	A(0,ρ) = ______dB U(vρ) = ______dB	fig. 6.5-10	par. 6.5.6.3
2.11	Calculate A(v,ρ)	A(v,ρ) = ______dB	A(v,ρ)= A(v,0) + A(0,ρ) + U(vρ)	par. 6.5.6.3 eq. 6.5-18
2.12	If rounding could not be estimated, determine A(v,o) from graph	A(v,o) = ______dB	fig. 6.5-8	par. 6.5.6.1

Worksheet 6.5-2. Diffraction Attenuation Calculations

3.1	Determine carrier wave length, λ	λ = ____km	$\lambda = 0.29979/f_{MHz}$	par. 6.5.5.1 eq. 6.5-9
3.2	Calculate $\sqrt{\lambda d}_{L1}$ and $\sqrt{\lambda d}_{L2}$	$\sqrt{\lambda d}_{L1}$ = ____km $\sqrt{\lambda d}_{L2}$ = ____km	λ, d_{L1}, d_{L2} in km	steps 1.8 &3.1 par. 6.5.5.2
3.3	Calculate $\|h_s - h_{s1}\|$ and $\|h_s - h_{s2}\|$	$\|h_s - h_{s1}\|$ = ____km $\|h_s - h_{s2}\|$ = ____km	h, h_{s1}, h_{s2} in km	steps 1.2 & 1.10; par. 6.5.5.2
3.4	If both $\sqrt{\lambda d}_{L1} \le \|h_s - h_{s1}\|$ and $\sqrt{\lambda d}_{L2} \le \|h_s - h_{s2}\|$, $G(\bar{h}_1) = G(\bar{h}_2) = 0$; go to step 3.18 (see paragraph 6.5.5.2 for additional discussion).			par. 6.5.5.2
3.5	If either one or both $\sqrt{\lambda d}_{L1} > \|h_s - h_{s1}\|$ and $\sqrt{\lambda d}_{L2} > \|h_s - h_{s2}\|$, continue (subsequent calculations to determine either $G(\bar{h}_1)$ or $G(\bar{h}_2)$, or both as required)			par. 6.5.5.2
3.6	Estimate effective antenna heights h_{e1} and h_{e2} as required	h_{e1} = ____km h_{e2} = ____km	from terrain profiles; sec. 6.5.3.1, item (k)	par. 6.5.3.1
3.7	Calculate a_1 and a_2	a_1 = ____km a_2 = ____km	$a_1 = d_{L1}^2/2h_{e1}$ $a_2 = d_{L2}^2/2h_{e2}$	par. 6.5.5.3 eq. 6.5-10a & b
3.8	Is path over sea water and polarization vertical?	If no, continue If yes, go to step 3.11		par. 6.5.5.3
3.9	Calculate $\bar{h}_1$ and $\bar{h}_2$	$\bar{h}_1$ = ____ $\bar{h}_2$ = ____	eq. 6.5-11a eq. 6.5-11b	par. 6.5.5.3
3.10	Go to step 3.17			
3.11	Determine K_o	K_o = ____	Use curve for sea water and vertical polarization	fig. 6.5-5; par. 6.5.5.4
3.12	Determine b	b = ____°	Use curve for sea water and vertical polarization	fig. 6.5-6; par. 6.5.5.4
3.13	Calculate C_{o1} and C_{o2}	C_{o1} = ____ C_{o2} = ____	$C_{01} = (8500/a_1)^{1/3}$ $C_{02} = (8500/a_2)^{1/3}$	step 3.8; eq. 6.5-12a & b
3.14	Calculate K_1 and K_2	K_1 = ____ K_2 = ____	$K_1 = C_{01}K_0$ $K_2 = C_{02}K_0$	steps 3.8 & 3.10 eq. 6.5-13a & b

Worksheet 6.5-3. Effects of Ground Reflectiom and Diffraction Loss

3.15	Determine $B(K_1,b)$ and $B(K_2,b)$	$B(K_1,b)$ = ______ $B(K_2,b)$ = ______	fig. 6.5-7	steps 3.11 & 3.12; par. 6.5.5.5
3.16	Calculate $\bar{h}_1$ and $\bar{h}_2$	$\bar{h}_1$ = ______ $\bar{h}_2$ = ______	eq. 6.5-14a eq. 6.5-14b	steps 3.7. 3.8, 3.14 par. 6.5.5.5
3.17	Determine $G(\bar{h}_1)$ and $G(\bar{h}_2)$	$G(\bar{h}_1)$ = ______dB $G(\bar{h}_2)$ = ______dB	as a function of K; use curve marked $K \leq 0.001$ except for vertical polarization over sea water	fig. 6.5-4; par. 6.5.5.5 & 6.5.5.5
3.18	Calculate total diffraction attenuation A_k	A_k = ______dB	use appropriate terms in eq. 6.5-6 as previously calculated	steps 2.7, 2.12, & 3.16 par. 6.5.4.2
3.19	Determine basic transmission loss L_b	L_b = ______dB	$L_b = L_{bf} + A_k + A_a$	step 3.17 & steps (40) & (41) from worksheet 4.4-5

NOTE: The calculations in these worksheets may be performed for various values of the effective earth radius a in order to obtain a time distribution of L_b as discussed in paragraph 6.5.7.3.

Worksheet 6.5-3 (continued)

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CHAPTER 7

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